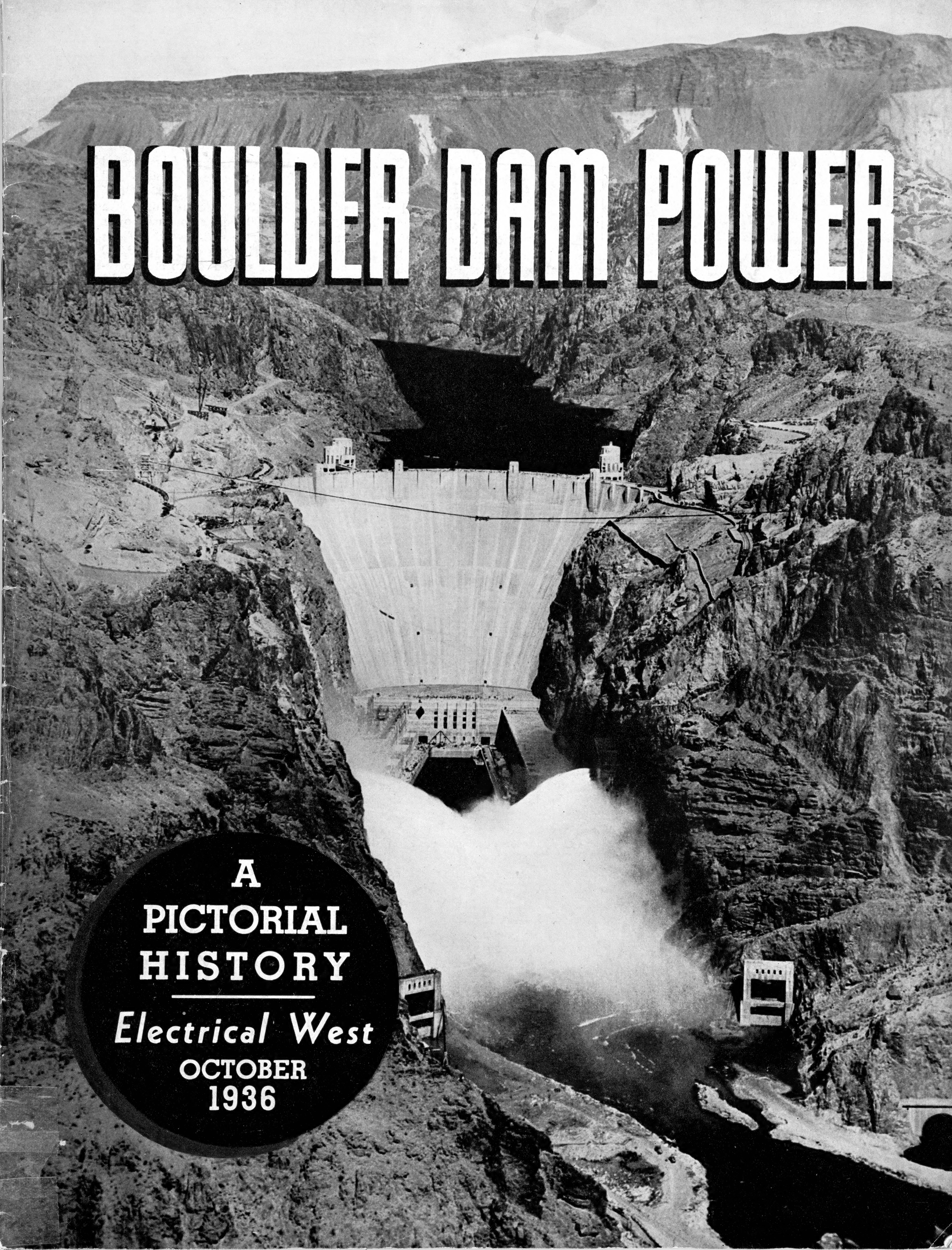
BOULDER DAM POWER



A PICTORIAL HISTORY

Electrical West

OCTOBER 1936

FROM DAM SITE

POWER from Boulder Dam.—A dream has become a reality. Across Black Canyon, some 30 miles southeast of Las Vegas, N. M., stands a mighty 726-ft. steel and concrete barrier impounding the waters of the great Colorado River in the natural reservoir created by centuries of its erosive action. By this massive piece of modern engineering, the waters of a 240,000-sq. mi. drainage area are diverted from wasteful and destructive liberty to useful and economic purposes.

From the engineering standpoint, the project is a study in superlatives. Boulder Dam is the highest yet constructed and creates the largest manmade lake in the world—a reservoir 115 miles long and containing 30,500,000 acre-ft. or an amount sufficient to provide 5,000 gal. for every human being on earth. Boulder power house, constructed just below the dam, has an ultimate capacity of 1,350,000 kva., by far the largest concentration of generating units in the world. For sheer size alone, the project would be of outstanding interest, but more important still are the economics involved in the effective utilization of Colorado River water and the pioneering in advanced engineering principles which paves the way for still greater achievements.

At the Black Canyon site, 30 years' stream gage records reveal an average runoff of 15,700,000 acre-ft., the maximum and minimum annual flow being 24,000,000 and 7,000,000 acre-ft., respectively. Characteristics of the river are its tremendous runoff, the high silt content of its waters, and the suddenness and severity of its floods which have dealt death and destruction in the Imperial Valley area.

As set forth in the authorization passed by Congress on Dec. 21, 1928, the purposes of the Boulder Canyon project were: (1) to regulate the flow of the Colorado River, provide adequate irrigation water and silt control for the rich farming areas in south-western Arizona and south-eastern California; (2) to insure an increased domestic water supply for municipalities of the Pacific southwest and to control release of stored waters for the above purposes, and (3) to generate power for sale to various distributing agencies in the surrounding states. Contracts for power and water sales at rates calculated to amortize the $165,000,000 principal and accrued interest over a 50-year period were consummated with these various agencies before the construction was started, thus insuring repayment to the federal government of the expenditures involved in the construction of the project. Corollary developments, made possible by Boulder Dam, are the $38,500,000 All-American Canal project (the cost of which is included in the above figure) required to bring Colorado River water into the Imperial Valley for irrigation and the $220,000,000 Colorado River aqueduct now being constructed by the Metropolitan Water District. The aqueduct will pick up 1,500 sec.-ft. from the river 150 miles below Boulder Dam and convey it across the desert some 290 miles to the coastal area of southern California.

Not all of the 30½ million acre-ft. of the reservoir behind Boulder Dam is useful storage. Nine and a half million acre-ft. must be reserved at all times for flood storage; 5 to 8 million acre-ft. reserved for a silt pocket, leaving only 12 to 15 million acre-ft. as dependable, active storage to release to the power house service. Based on a 16,000,000-acre-ft. average annual release for all purposes, at the average head of 530 ft., 4,330,000,000 kw.-hr. of firm energy (equivalent to 665,000 continuous horsepower) and 1,550,000,000 of secondary energy would be produced by falling water.

Based on the 16,000,000-acre-ft. annual runoff, water allocation was made as follows: 7,500,000 acre-ft. to the upper basin states, and 7,500,000 acre-ft. to the lower basin states, with the right of the latter to increase their beneficial consumption use of such water by 1,000,000 acre-ft. per year. California is given the right to use one-half of surplus water available above 7,500,000 acre-ft.

Contract price for firm power is 1.63 mills per kw.-hr. for falling water delivered at the power house transmission voltage and 5 mills per kw.-hr. for secondary power delivered at the power house transmission bus. The annual income from the sale of power and water is expected to be $7,400,000, of which $6,550,000 comes from firm power, $650,000 from secondary power and $250,000 from water sales. At this rate the gross income of $351,000,000 over a 50-year period is expected to return the principal and interest on the original investment, permit a sinking fund to take care of depreciation, pay the operating and maintenance expenses of the structures and provide a surplus which is to be allocated 62½ per cent to the United States and 18¼ per cent each of the states of Arizona and Nevada.

To the United States Bureau of Reclamation fell the responsibility for the design, supervision of construction, and the actual installation of all the machinery and apparatus in the dam, spillways and power house. Actual construction was carried on by the Six Companies, Inc., a San Francisco organization, on a labor contract basis.

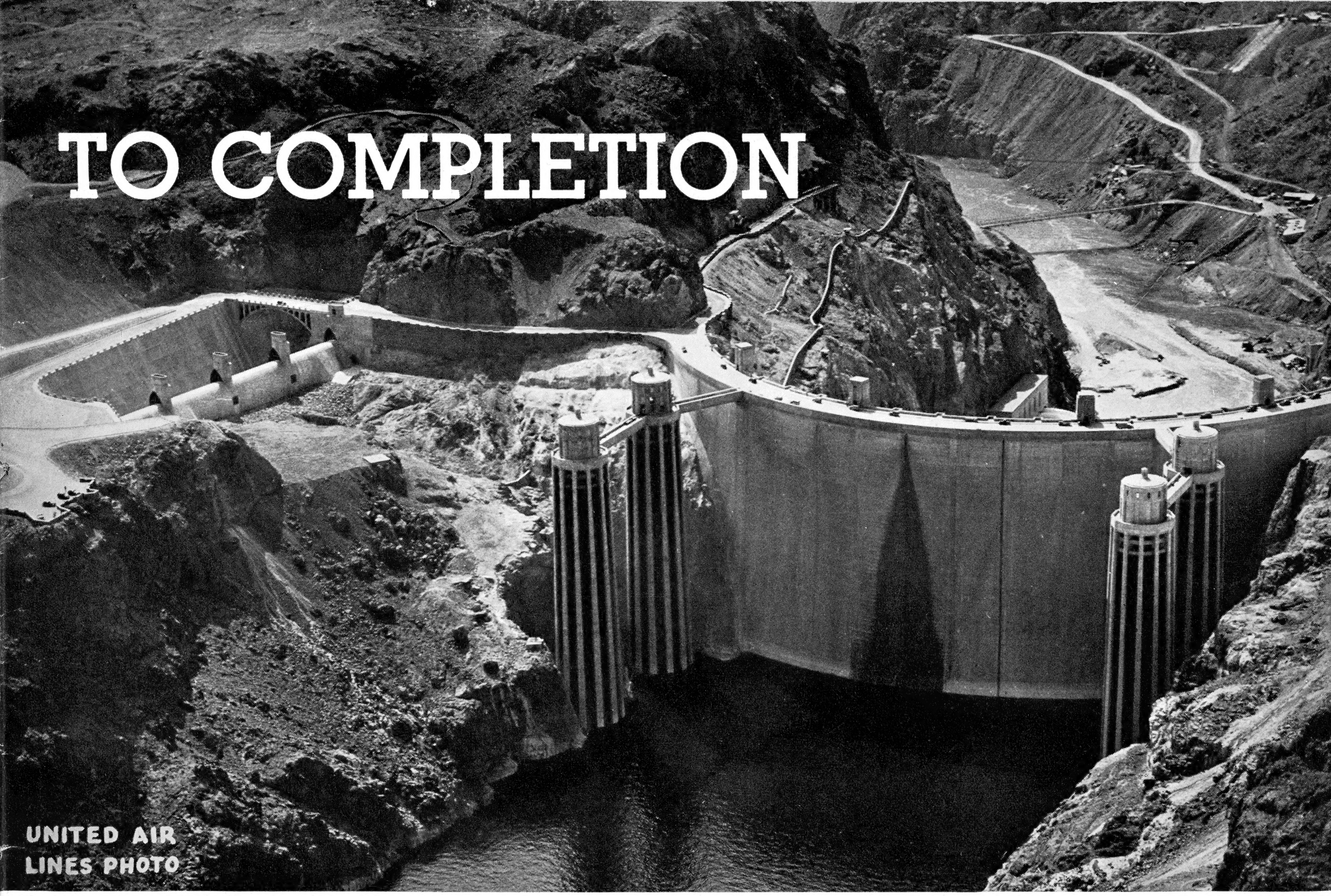
That the first power from the project was generated just slightly over 5 years from the date of starting the diversion tunnels and 2 years ahead of the schedule is a tribute to the efficient coordination and careful engineering that has characterized the project from its inception. In no other way could such record-breaking progress have been made in the face of the tremendous natural difficulties which characterized the location.

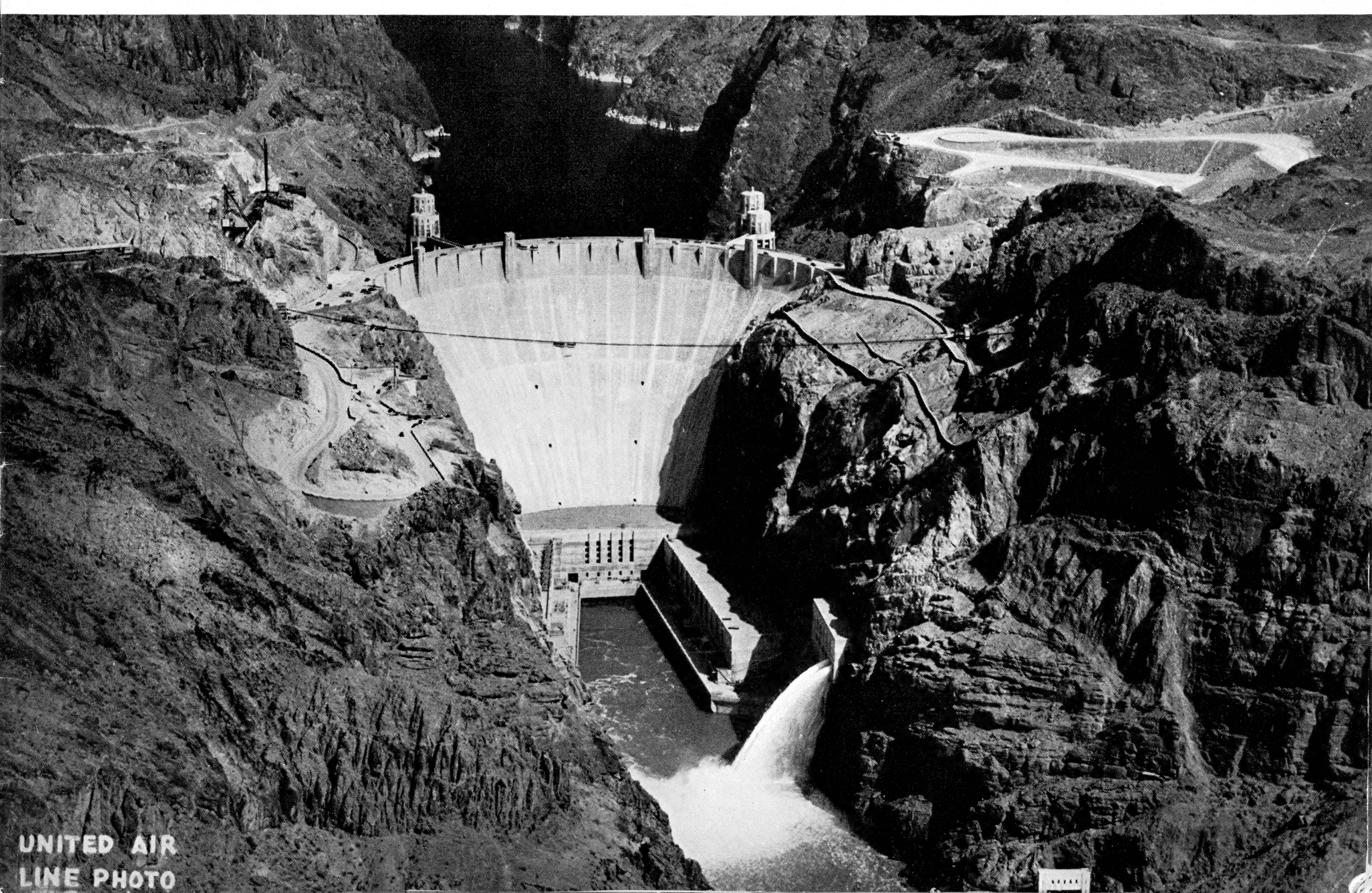
Modern engineering conquered these difficulties. Modern construction equipment permitted man-power to be utilized more effectively than ever before. Advanced design made the utilization of Colorado River energy economically feasible. Those who worked upon the project, watched it rise to the magnificence of its completed shape, lived its progress from day to day, can fully appreciate its magnitude and the multiplicity of details its successful completion represents. As a permanent record of construction technique and engineering design employed from dam site to completion, Electrical West presents this pictorial history of the project.

Boulder Dam Power Distributing Agencies

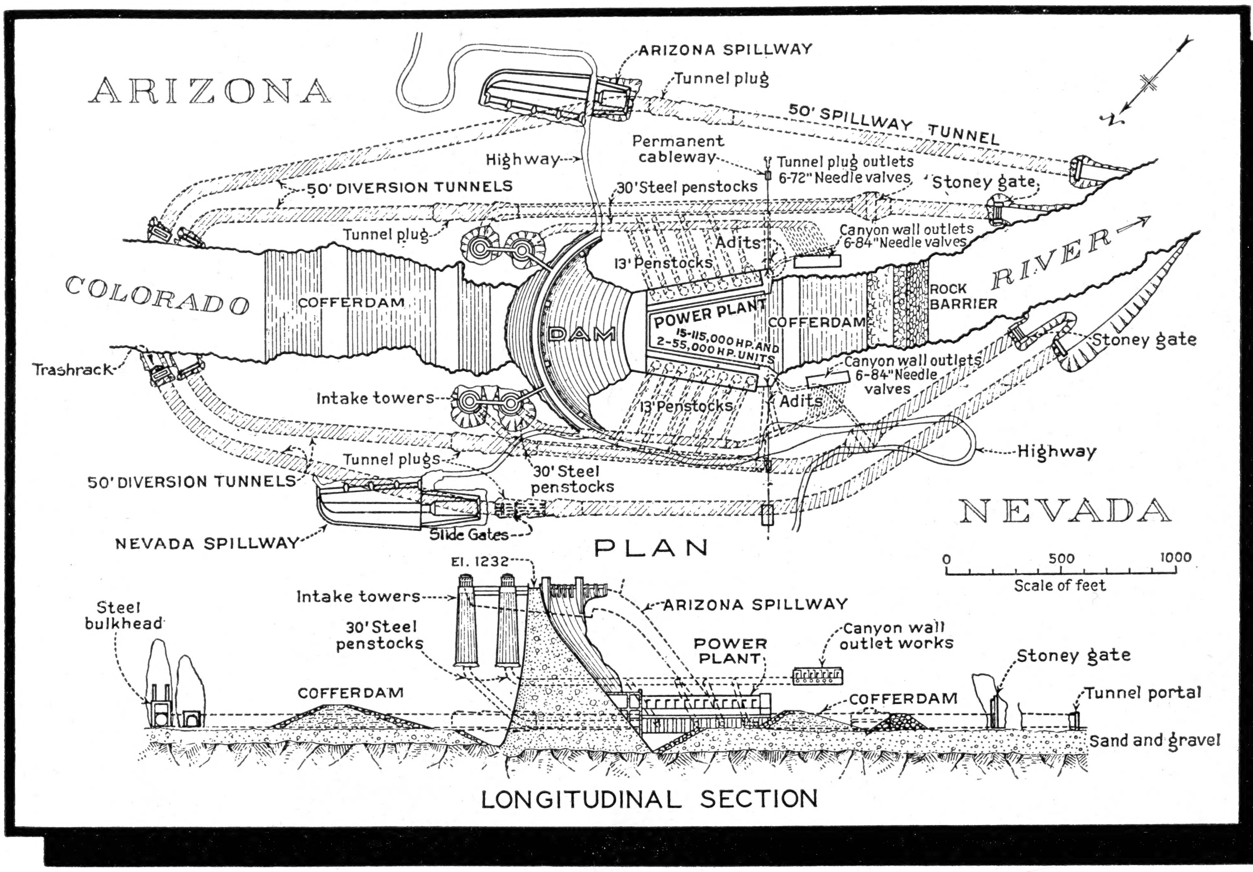
Company	Firm Power Contracts (Kw.-Hr.)	Approximate Annual Payment at 1.63 Mills
Southern California Edison	917,000,000	$1,495,000
City of Los Angeles	1,485,000,000	2,420,000
Los Angeles Gas & Electric	114,000,000	185,000
Southern Sierras Power	114,000,000	185,000
Pasadena, Glendale, Burbank	174,000,000	284,000
Metropolitan Water District	1,526,000,000	2,481,000
Total	4,330,000,000	$7,050,000

TO COMPLETION





PRELIMINARIES . . .

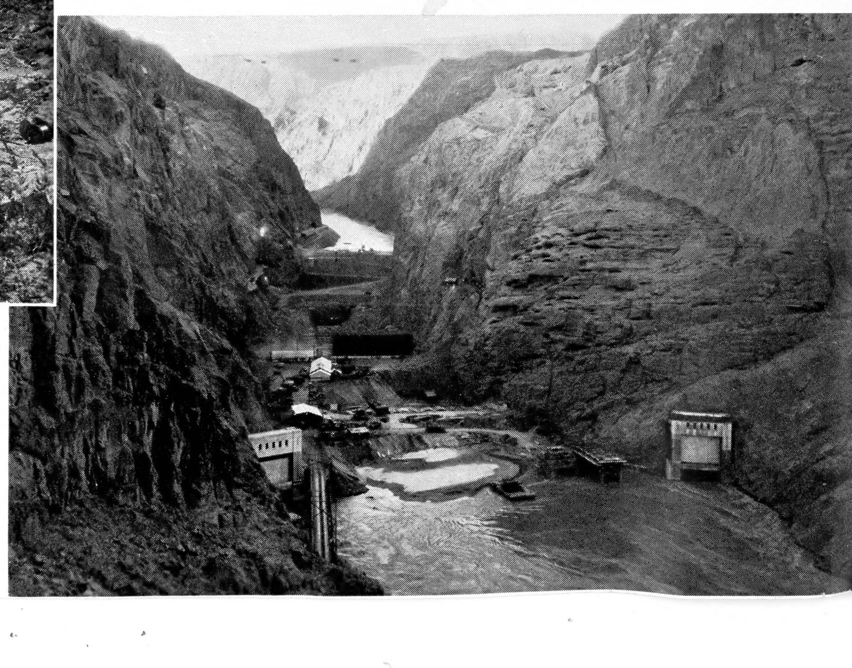


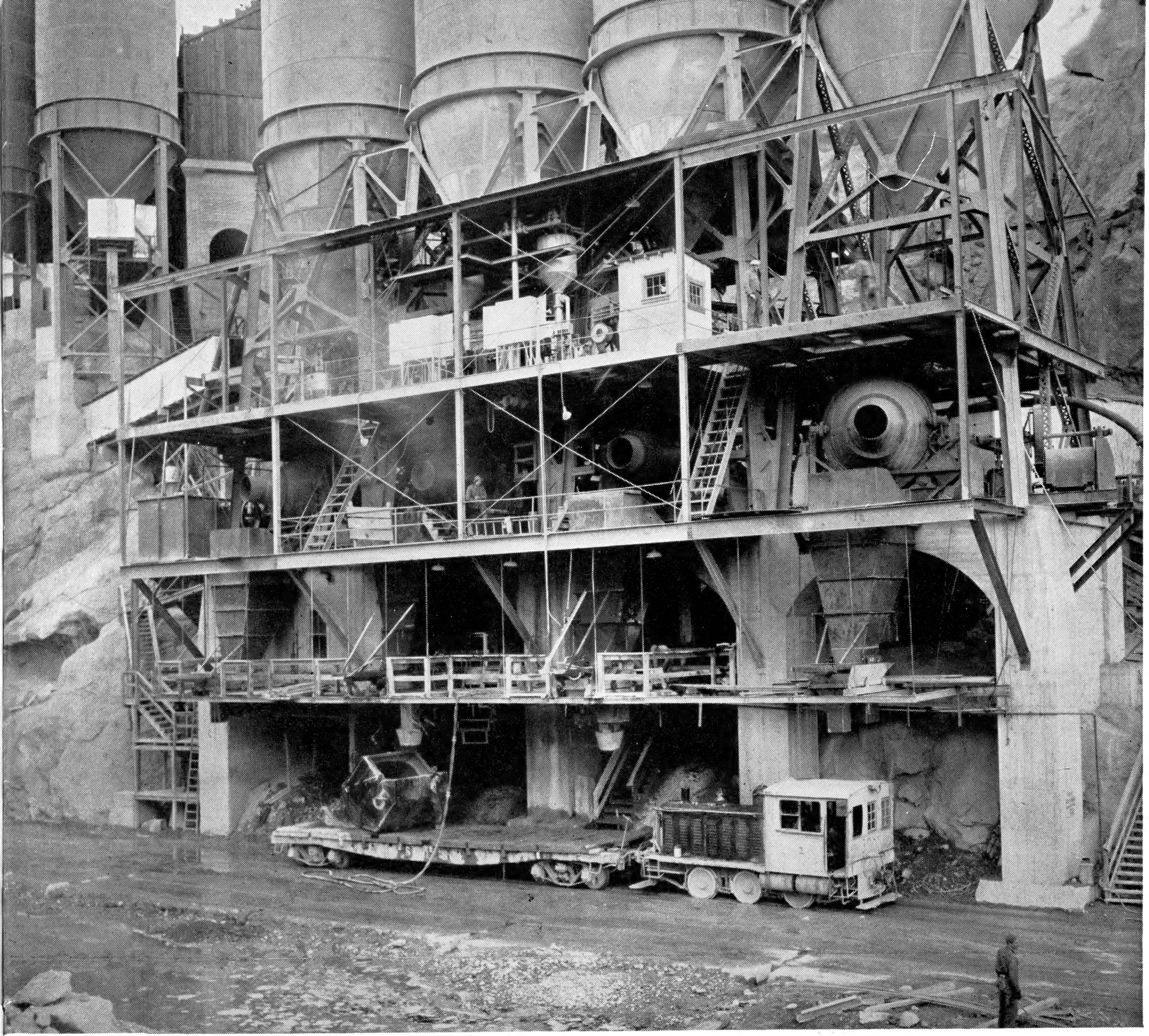
General Plan and Longitudinal Section of the Boulder Canyon Project. First constructed were the four 50-ft. diversion tunnels, two on either side of the canyon at Elevation 649. Upper and lower coffer dams permitted unwatering of the construction site, the river flow being carried around the project in the diversion tunnels. The outer diversion tunnels later were connected by inclined shafts to the spillways and plugged upstream from the entrance of the tunnel connecting the spillways to the diversion tunnels. Thirty-foot steel penstocks are installed in the inner diversion tunnels connecting the upstream intake towers with four branch penstocks supplying four of the main generating units in each wing of the power house. The penstocks then continue to discharge chambers in the diversion tunnels where six 72-in. needle valves permit release of additional water other than that passing through the turbines.

At Elevation 820 ft. in 37½-ft. diameter tunnels on both sides of the river are installed 30-ft. diameter steel penstocks connecting the downstream intake towers with the remaining four branch penstocks in each power house wing. The upper penstocks continue to the canyon wall outlet valve houses down stream on either side of the canyon way and terminate in six 84-in. needle valves. Each spillway can handle 200,000 sec. ft. of water, the four sets of needle valves 100,000 sec. ft. and the fifteen 115,000-hp. turbines and two 55,000-hp. turbines, 25,000 sec. ft. making possible a total release from the reservoir of 525,000 sec. ft.

Construction Power had to be transmitted 222 miles from San Bernardino, Calif., over a 110-kv. transmission line built for the purpose by the Southern Sierras Power Co. This is the substation built on the canyon rim above the damsite from which power was supplied for all construction activities and for the requirements of Boulder City, seven miles away.

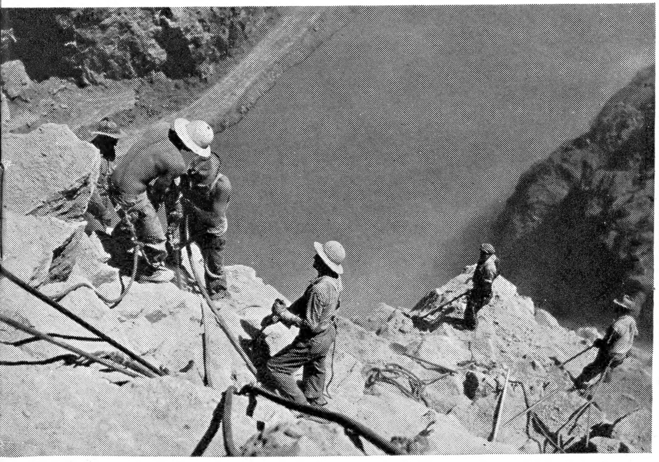
Unwatering the damsite preparatory to excavating to bed rock. The river may be seen entering the two inner diversion tunnels which discharge the flow below the downstream coffer dams.



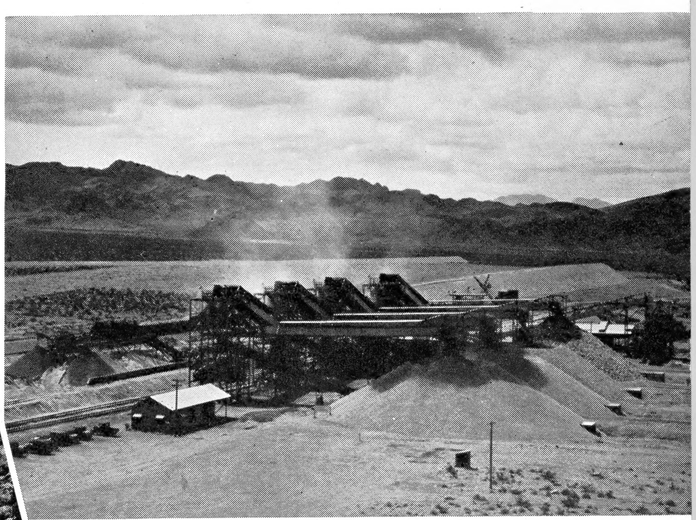


Concrete Mixing Plants were vital as the project required 4,200,000 cubic yds. of concrete. Skill in design and operation were essential to enable rapid delivery of concrete. This view of one of the two main batching plants shows, at the top, the main storage bins for cement, sand and aggregate. Proportions were weighed at the top platform, dropped into four 4-yd. mixers immediately below and emptied into hoppers for delivery to concrete buckets carried on flatcars at the ground level. Operations were practically automatic, making possible delivery of 2,200 yd. of mixed concrete per shift.

Scaling. Hundreds of feet above the river, scalers and drillers stripped the walls of loose soil and rock and drilled the powder holes necessary for blasting abutment foundations. A hazardous job to remove future hazards from falling rock.

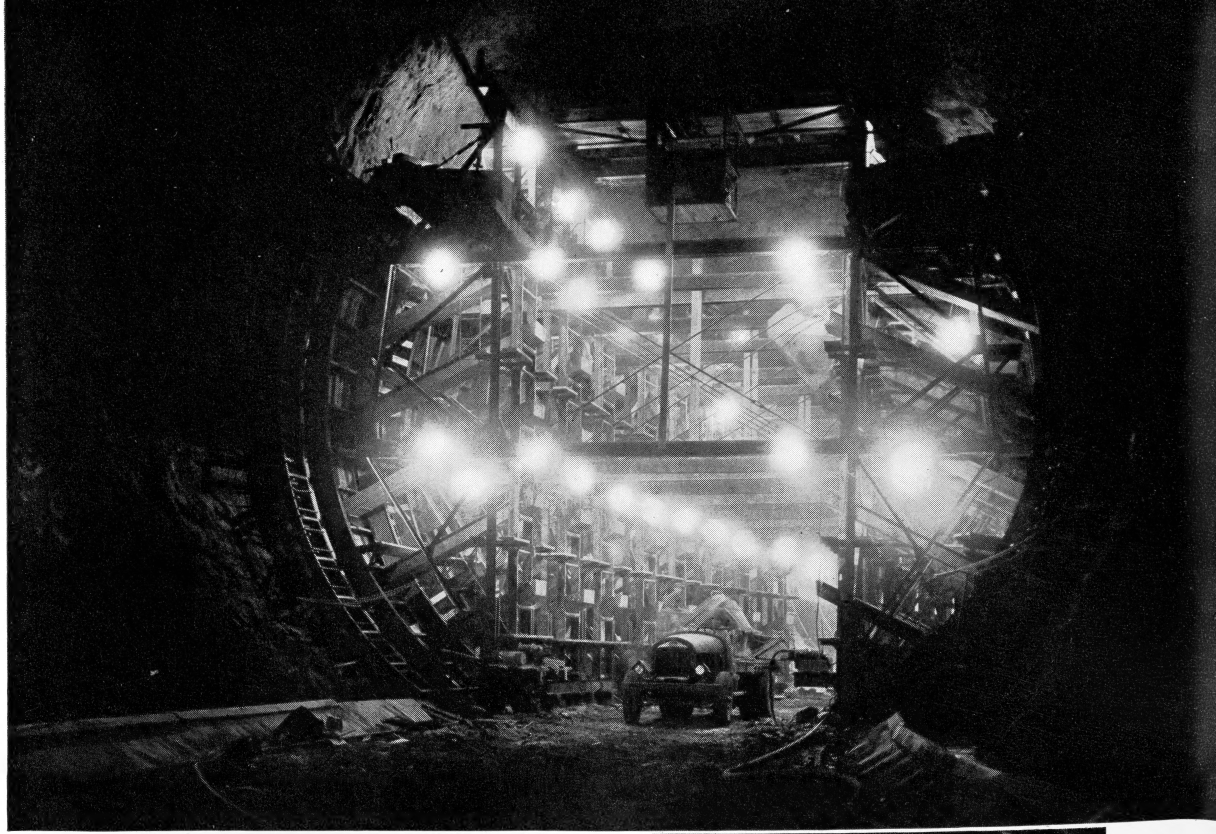


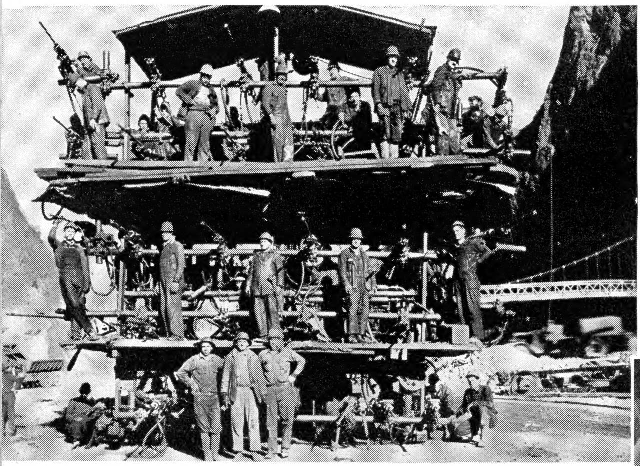
Blasting operations on a large scale were necessary to insure a solid foundation for the base and abutments of the dam in the hard, durable rock (andesite breccia) through which the Colorado has cut the canyon. Bed rock was located between 110 and 130 ft. below low water level.



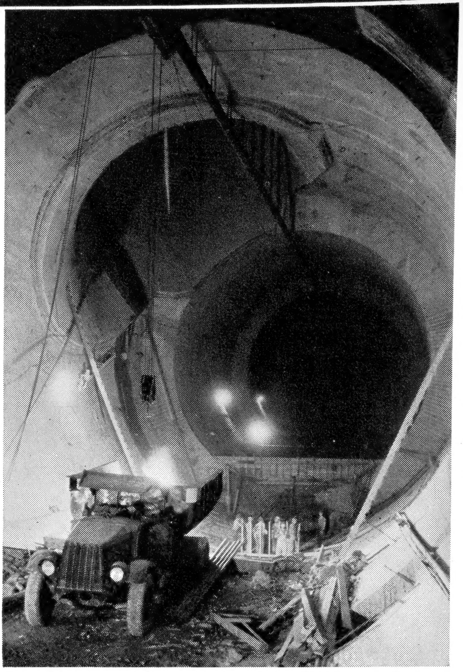
Aggregate Plant— the desert provided an ample supply of sand and rock for concrete mixing operations. This huge gravel plant, having a capacity of 700 tons per hr., was located in a dry sink one mile upstream from the damsite. Today, this area is far below the surface of Lake Mead formed by the dam.

TUNNELS



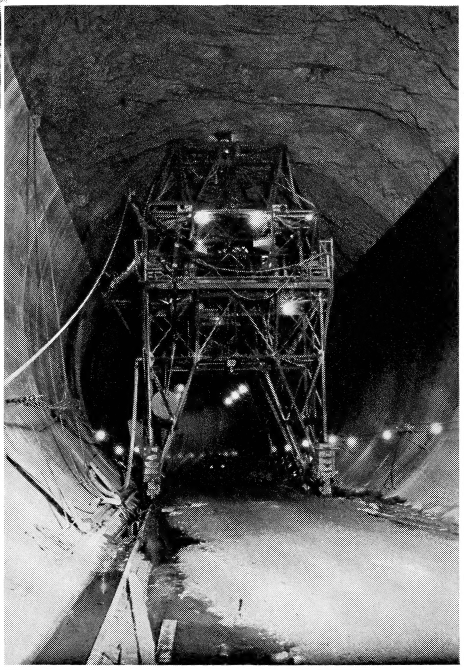


Lining the diversion tunnels with a 3-ft. surface of concrete was expedited by moveable forms such as the one shown here for pouring the tunnel walls. The arch or top section lining was accomplished by forcing the concrete into the forms under air pressure.

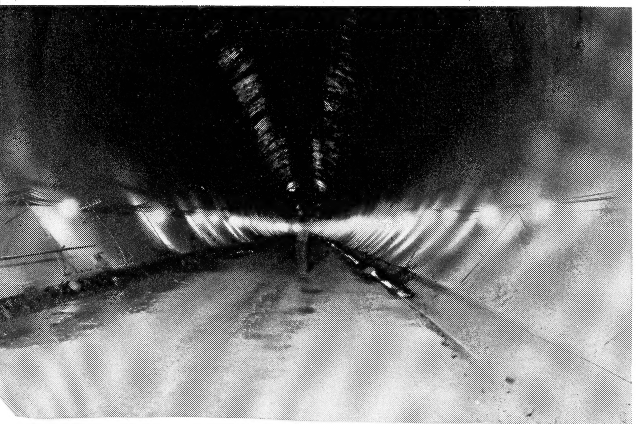


Boring Powder Holes to blast down the face of the 56-ft. tunnels in solid rock required special tools to speed progress. Here is a drilling jumbo, as its name implies, a huge machine which moved to the face of the tunnel and drilled more than a score of 10-ft. powder holes in the face by means of gang of automatic, pneumatic drills. Holes were charged, detonated and the material blown down from the face removed by dump trucks —a cycle repeated many times in driving the three miles of diversion tunnels.

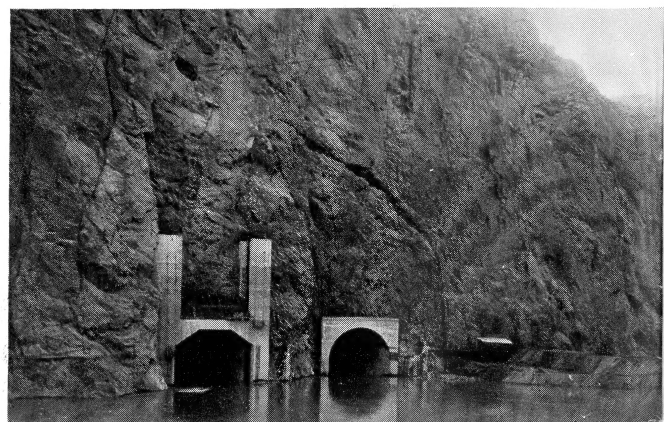
Working on the arch section of a 56-ft. tunnel is easy with this jumbo shown at the right which was used for a variety of purposes such as "trimming" the rock ceiling, setting forms, etc. Manpower was multiplied many times by such machines.

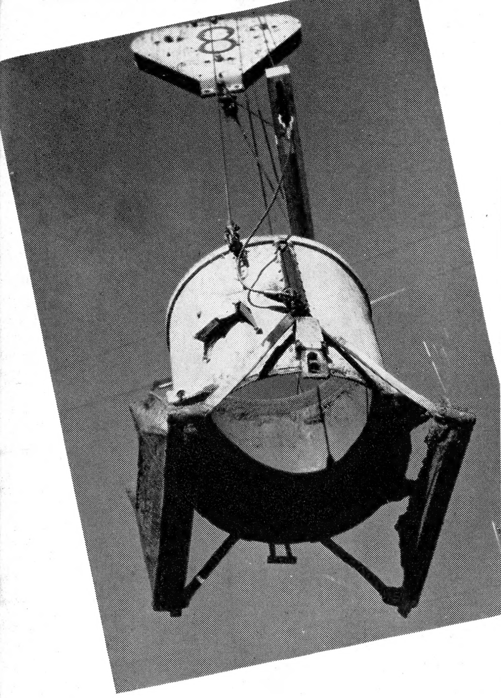


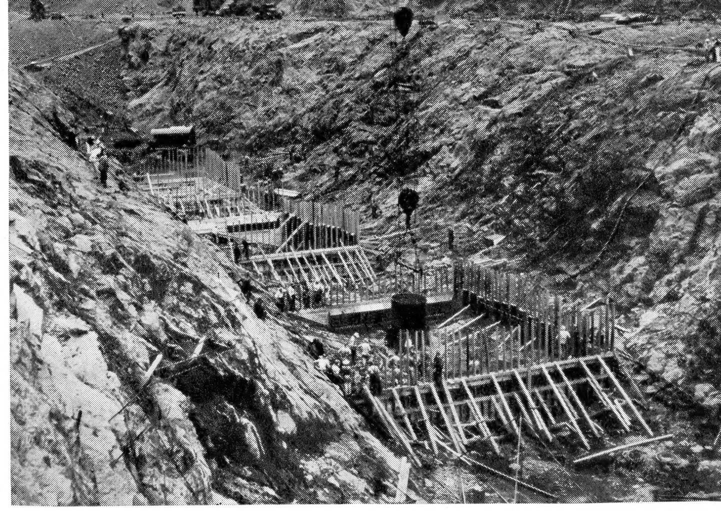
Junction of the tunnel (entering at upper left) joining the upstream intake tower with the inner diversion tunnel. When work had progressed to the point where the tunnel was no longer needed for diversion, permanent concrete plug was placed upstream just beyond this point and a 30-ft. diameter steel penstock installed joining the intake tower with the four branch penstocks leading to generating units and continuing to the downstream release valve chamber near the lower end of the diversion tunnel.



Completed diversion tunnel (left) and (right) the Colorado River flowing through the two Arizona diversion tunnels during the early stages of construction. During construction the Colorado obligingly dropped to its alltime recorded low although the four diversion tunnels had a capacity of 800,000 sec. ft.

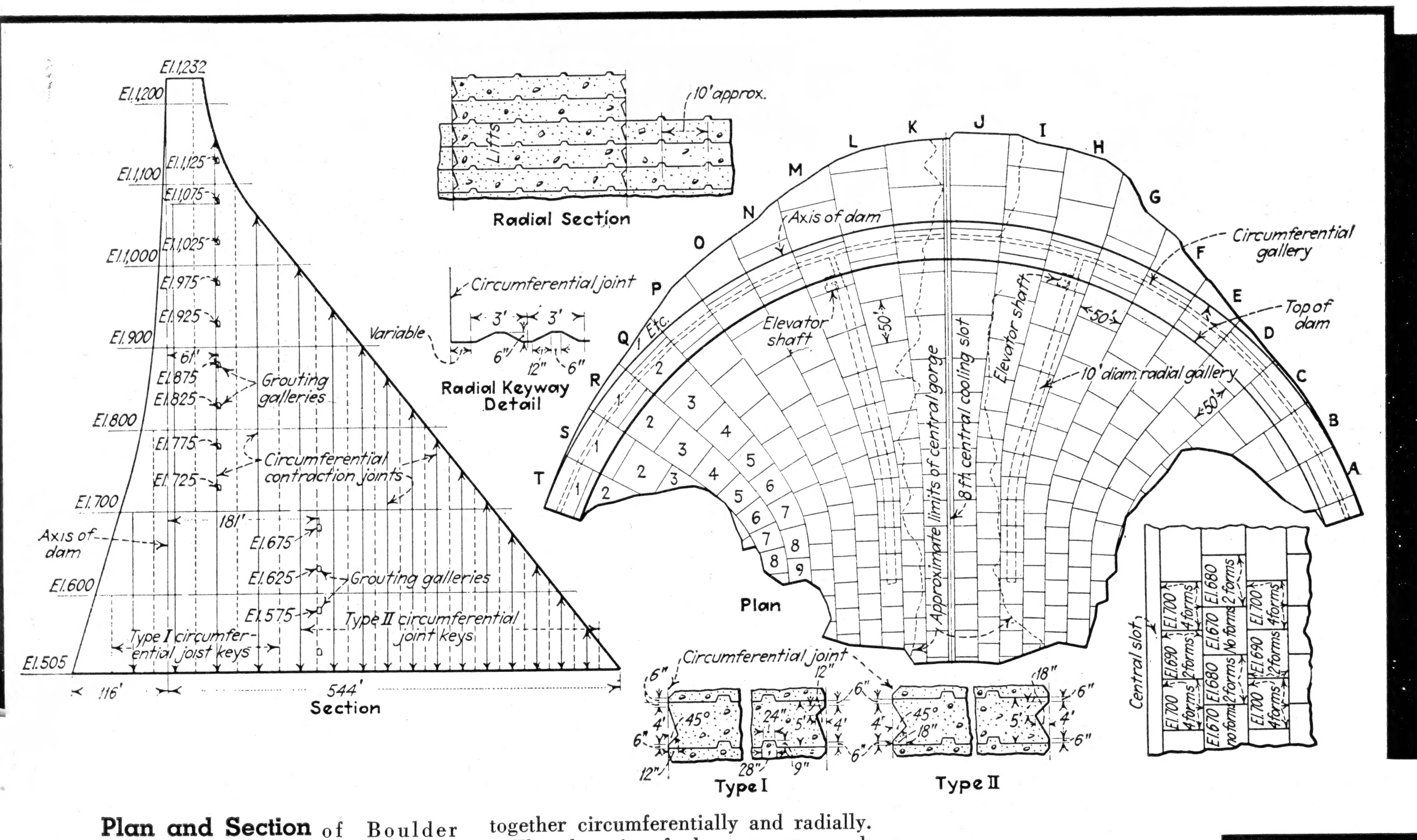






First Bucket of concrete (above) being poured in Boulder Dam. From this point activities accelerated until the peak placement of 10,462 cu. yd. of concrete daily was reached.

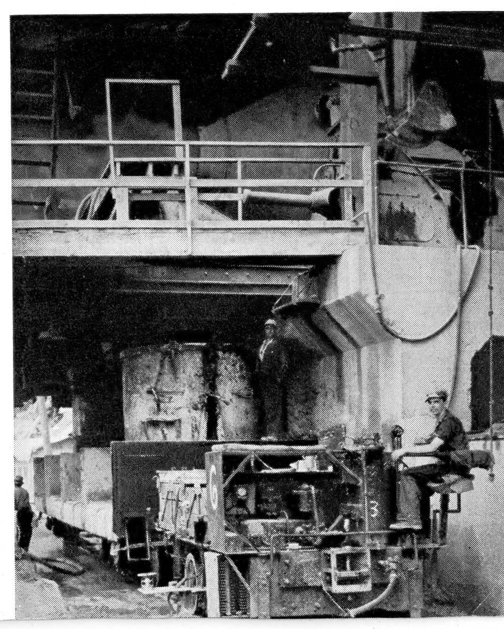
Bottom Dump Bucket (left) of 8 cu. yd. capacity solved the problem of uniformity in concrete placing by spreading the wet concrete over large areas on a "live" surface. (Center) Buckets were transported by cableways which picked them up at the canyon rim from special flatcars and carried them to the forms, and back again to the flatcar.



Plan and Section of Boulder Dam showing how the 3,400,000 yd. mass of concrete was built up in a series of columnar blocks. Note the variations in size of the columns between upstream and downstream faces of the dam. Columns were keyed together circumferentially and radially.

The dam is of the concrete, arch gravity type, weighs nearly 6,600,000 tons. Height 727 ft., thickness at base, 660 ft.; crest 45 ft.; length along crest, 1180 ft. Maximum water pressure at base, 45,000 lb. per sq. ft.

Concrete Transportation was accomplished by five cableways spanning the canyon. Four of these had moveable self-propelling towers on each side of the canyon, the towers running on tracks parallel to the canyon edge to afford complete coverage of the damsite pouring operations. The fifth had a fixed headtower on the Nevada side and a moveable tail tower on the Arizona side moving on a radial track to give coverage of the power house concrete placement. (right) Concrete buckets, hauled on flatcars by storage battery locomotives, were moved to positions along the canyon walls and rim and swung down into the forms in the canyon by the cableways.

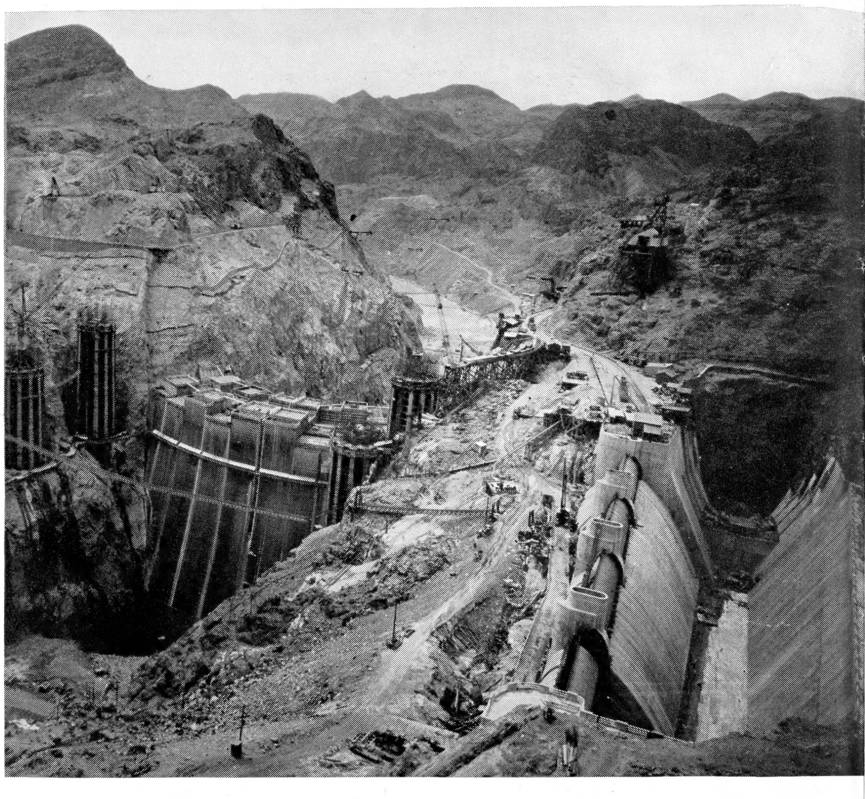


Progress was measured in 5-ft. stages. This view of the downstream face illustrates the construction method used which consists of interlocking vertical columns varying in size from 25 by 30 ft. to 55 by 60 ft. near the upstream face. Alternate rows of columns are maintained at different heights horizontally and longitudinally, the upstream row columns always being higher than adjacent downstream columns. A maximum variation of 35 ft. in surface level and a maximum increase in height of 5 ft. in 72 hr. was permitted as a means of controlling the uniformity of concrete and simplifying form construction. By using this method of construction only the highest columns in the highest rows require forms on all four sides, the surface of these higher columns providing two or more surfaces against which lower blocks are raised. As the elevation increased abutment blocks gradually assumed columnar forms and were included in the "step" program.

Although the time required to pour a 5-ft. "lift" for a 25 x 30 ft. column was approximately 1½ hours, the time restrictions did not slow the job down because of the large area covered by the dam which enabled pouring operations to be shifted to other columns. A field check was made every morning to check heights of all columns and correct those which were out of line.

When the height of the dam had reached elevation 920 ft., operations of the low-mix plant and the railway trestles along the canyon wall over which trains of concrete buckets were hauled to the cableways had to be abandoned because of the formation of the reservoir. All operations then were carried on from the hi-mix plant.

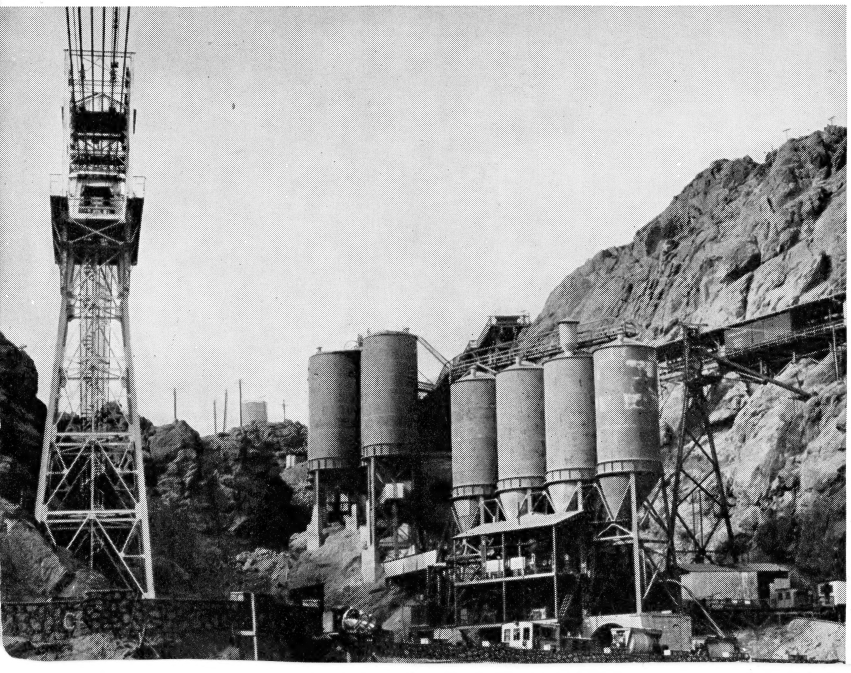
This photograph is unusual in that all of the carriages of the five moveable cableways described on the preceding page are shown over the damsite.

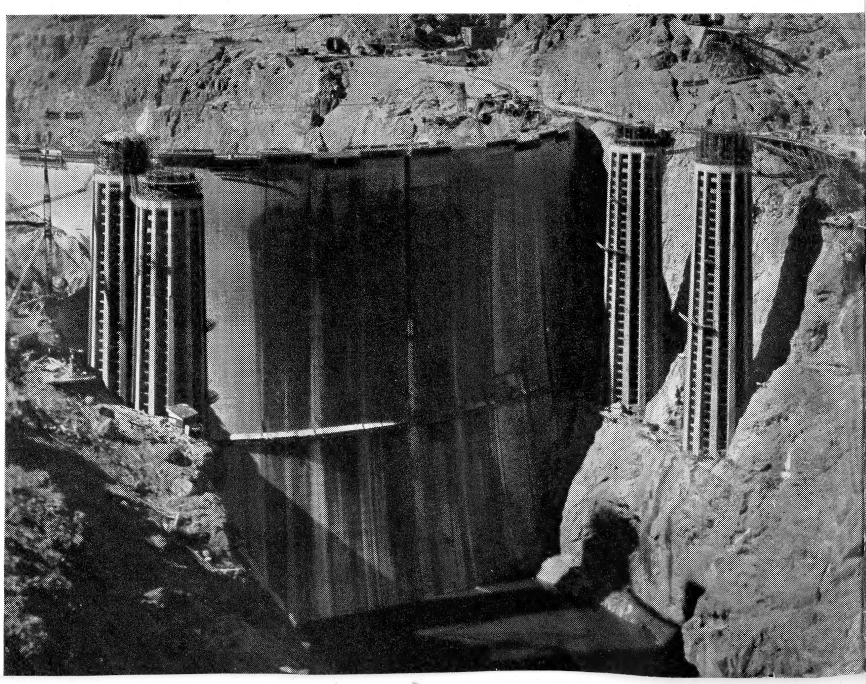


CONSTRUCTION

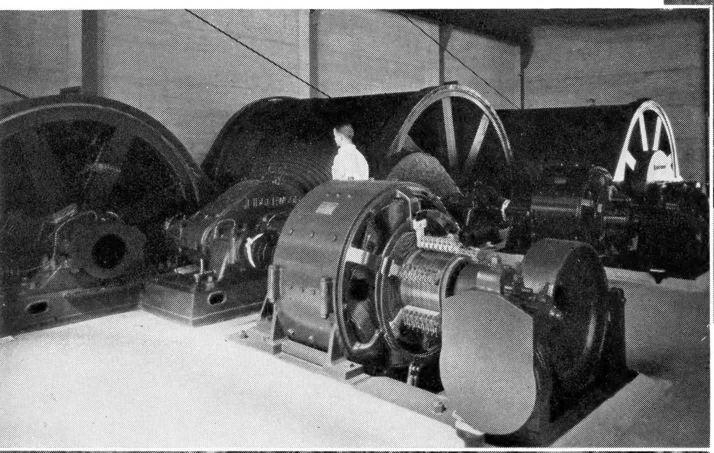
Intake Towers (lower right) rise with the dam. The base of these towers, each of which will contain two cylindrical gates, is at elevation 894, 369 ft. above the base of the dam.

Hi-Mix Blending Plant (lower left) and headtower of the 150-ton permanent cable-way built by the Government. The blending plant not only mixed concrete but also delivered dry cement to the low-mix concrete plant a distance of more than a mile by a compressed air delivery system.

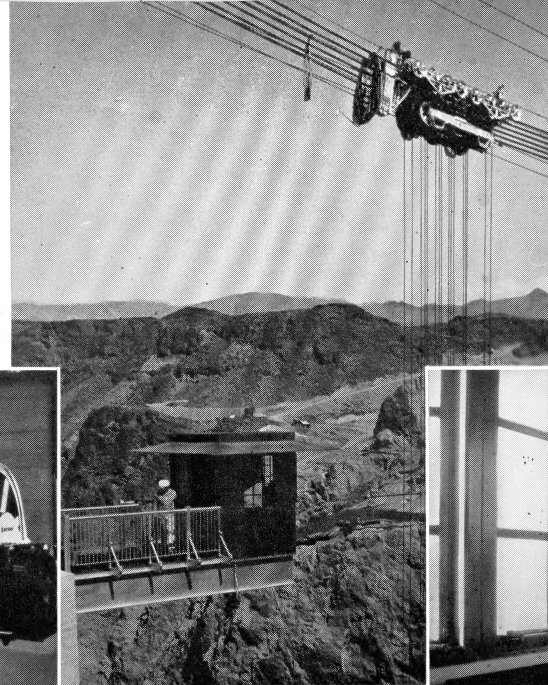


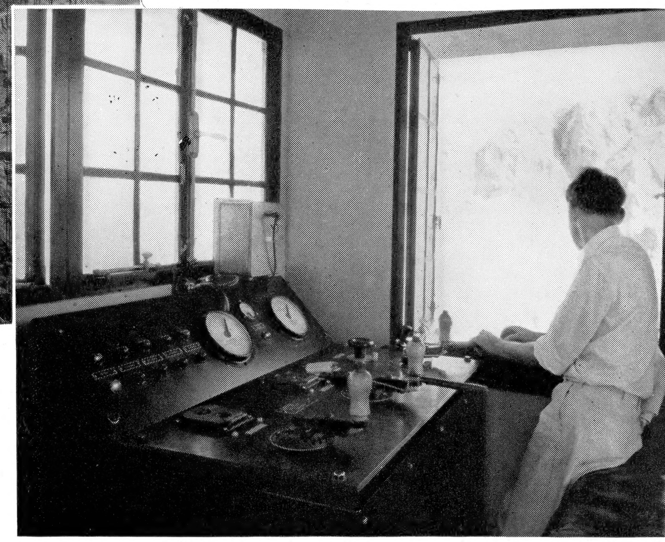


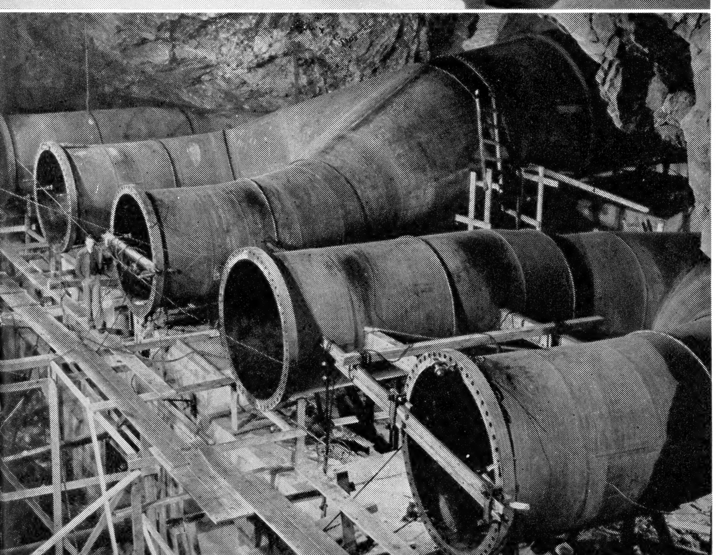
150-Ton Hoist House (below) for the permanent cableway built to transport penstock sections and power house equipment from the rim into the works in the canyon. The carriage consists of 48 wheels riding on six 3½ in. cables and sheaves sufficient to provide a 16-part tackle for 150-ton loads.



Cableway Control House (left) extends out over the canyon rim so that operator (below) can observe movement of the hoist. The hoist serves four loading platforms at points within the canyon and the control may be transferred to any loading platform through interlocking changeover switches if desired.



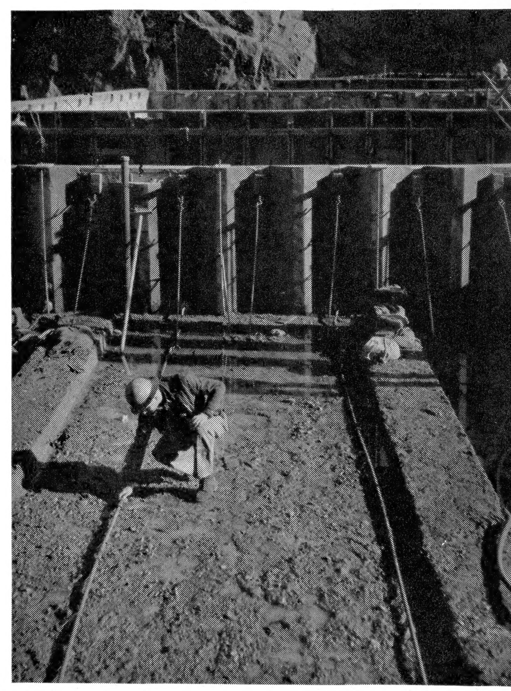




Canyon Wall Outlet Valves—this view shows the downstream terminal of the upper penstock during construction. Each of these branches will be connected to 84-in. needle valves to be used for emergency discharge around the dam. There are two such outlet works, one on either side of the canyon 180 ft. above the river level. Lower penstocks discharge through 72-in. needle valves located in a chamber in the downstream diversion tunnel.

A Cooling System to dissipate heat generated in the "setting" of the concrete was necessary to bring the mass of concrete in the dam to a uniform temperature so that grouting could be expedited and future cracking eliminated. 300 miles of 2-in. steel tubing (right) to carry the refrigerant was imbedded in the dam spaced at 10-ft. vertical intervals and 11 ft. horizontal intervals. Two separate cooling systems were used. Immediately after the "pour" river water, reduced to 70 deg. F. by being passed over the huge cooling tower (lower left) was circulated through the pipes which were connected to 14-in. headers running longitudinally through the 8-ft. slot in the center of the dam (lower right). When the next "lift" was made, the river water was diverted to the header serving that level and refrigerated water at 44 deg. F. from the 1,000 ton refrigerating plant (center below) was circulated through the first system to bring the concrete down to final temperature of approximately 70 deg.

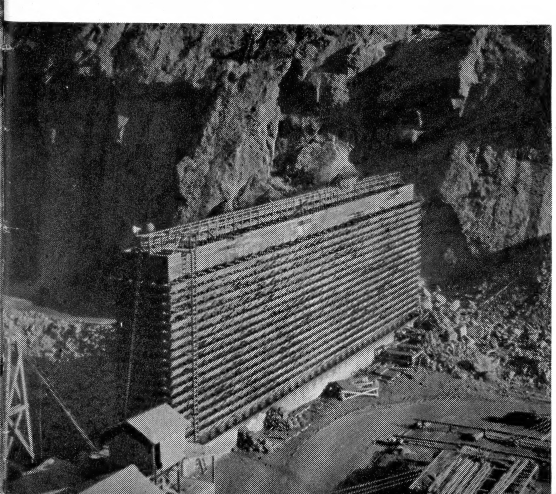
It was estimated that it required the removal of 38,600 B.t.u. for each of the 3,350,000 cu. yd. of concrete in the dam to accomplish this.

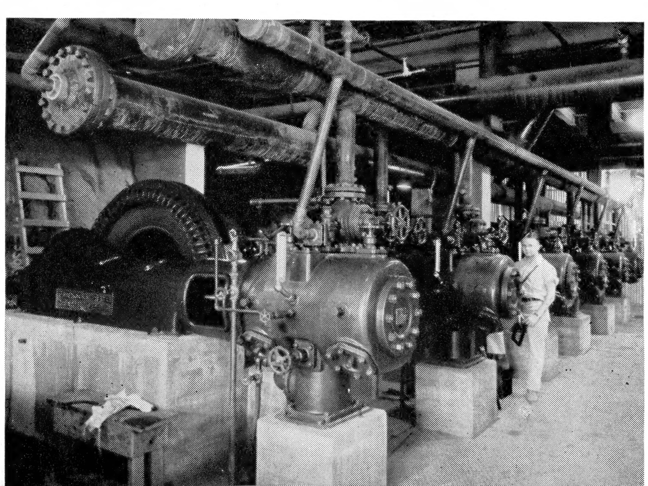


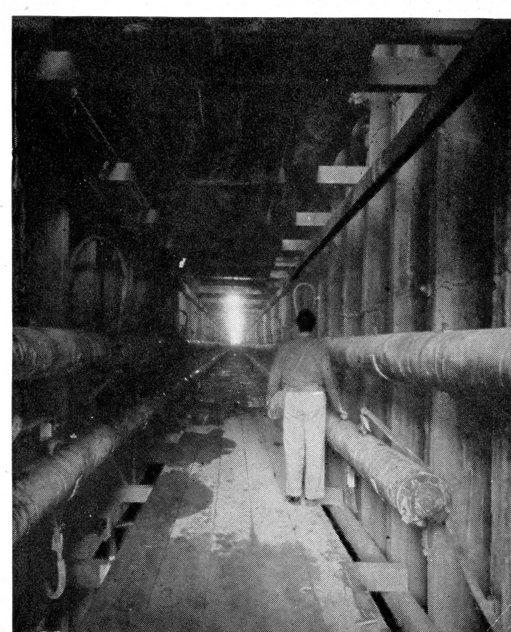
Cooling Tower built of redwood on the lower coffer dam is 160-ft. long, 16-ft. wide and 45-ft. high, and proved effective due to the low humidity and natural draft in the canyon. 6,000 g.p.m. were cooled to temperatures as low as 65 deg. F.

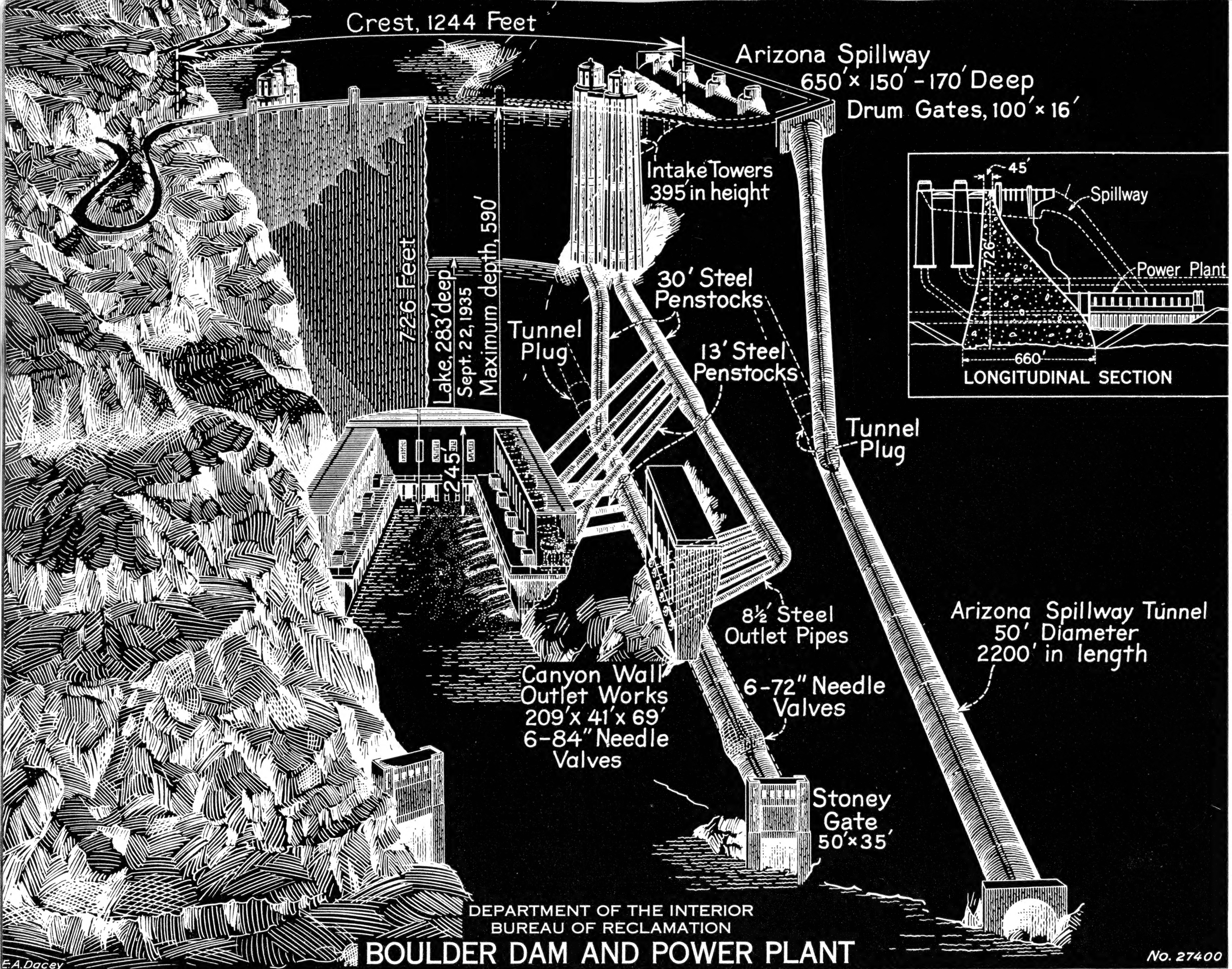
Refrigerating Plant utilizes three 275-ton compressors which were remodeled from air compressors used in driving diversion tunnels by substituting ammonia cylinders for air cylinders. Refrigerated water at 44 deg. F. entering the cooling system of the dam returned to the plant at 74 deg.

Piping for the cooling system supply to the dam consisted of four 14-in. headers carried in an 8-ft. slot through the center of the dam. These headers fed supplementary 6-in. headers of both cooling circuits.



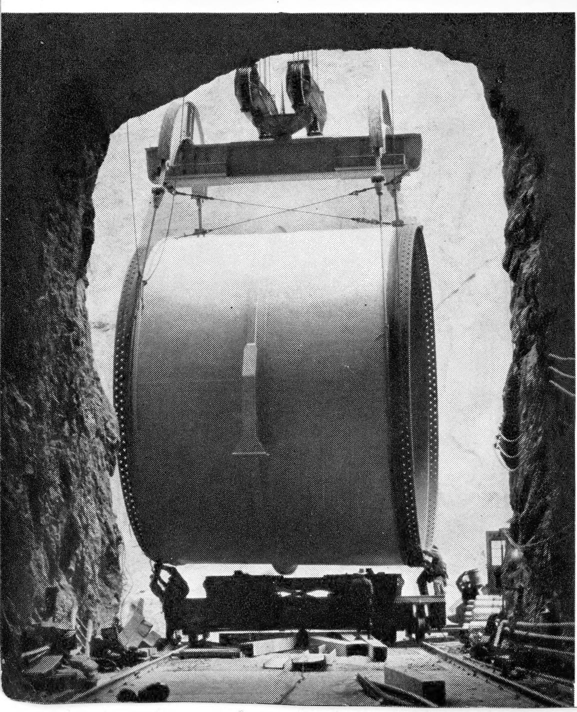


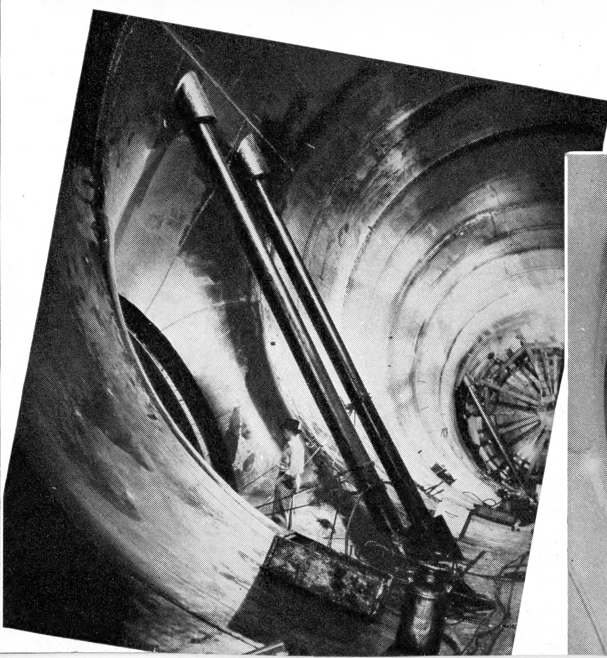




Cutaway View showing the Arizona penstock layout which is duplicated in all essentials on the Nevada side. In the four diversion tunnels, two of which are shown in perspective, are installed 30-ft. steel penstocks, the outer tunnels being connected with the spillways and the inner tunnels with the upstream intake towers. Another pair of 30-ft. penstocks, installed in the upper 37½-ft. tunnel join the downstream intake towers with the canyon wall outlet valve houses. From the lower inner penstock and the upper penstock four 13-ft. branch penstocks of each serve the powerhouse turbines. At the downstream end, the upper penstock terminates in six 8½-ft. penstocks connecting with the needle valves in the outlet house.

Penstocks are constructed from steel plate varying in thickness from .625 in. to 2¾ in. As the 30-ft. diameter sections for the upper end of the penstock weigh as much as 150 tons and because of their size, the sections had to be fabricated on the site in a special plant built by the Babcock & Wilcox Co. Steel was shipped from eastern plants in flat plates, the largest of which weighed 23 tons. Two such plates constituted a flatcar load. Three of these plates, 32-ft. long, 12-ft. wide and 2¾-in. thick were fabricated into a 12-ft. section of 30-ft. diameter penstock. Plates were marked for pattern, placed in a special cutting machine which also cut a beveled edge necessary for welding, welded, inspected by a special X-ray machine and then heated to relieve stresses. Required for the installation were 4,700 ft. of 30-ft. diameter penstock; 1,900 ft. of 25-ft. diameter; 5,600 ft. of 13-ft. diameter and 2,300 ft. of 8½-ft. diameter penstocks all of which was fabricated at the Boulder plant of B. & W.





Finished Penstock section, giving some conception of its size by comparison with the man standing at the left.

Rolling Plates to shape in the most powerful machine ever designed for this purpose. The rolls can impose a load of 3,500,000 lbs. on the plate and can handle plate up to 2¾ in. in thickness. Where special conical sections were required, the plates were rolled after being bulldozed into required shape by two 1,500-ton presses working together as a unit.

When the section has been shaped and the edges brought together, it is spotwelded and placed in the automatic welding machines which consist of automatic welding heads mounted on gantry units to provide flexibility. Welding rod, fed through the head automatically, comes in 12-ft. lengths with threaded ends so that new sections could be added without interrupting the continuity of the process. Approximately 700,000 linear feet of welding were required to fabricate 45,000 tons of penstock used on the project.

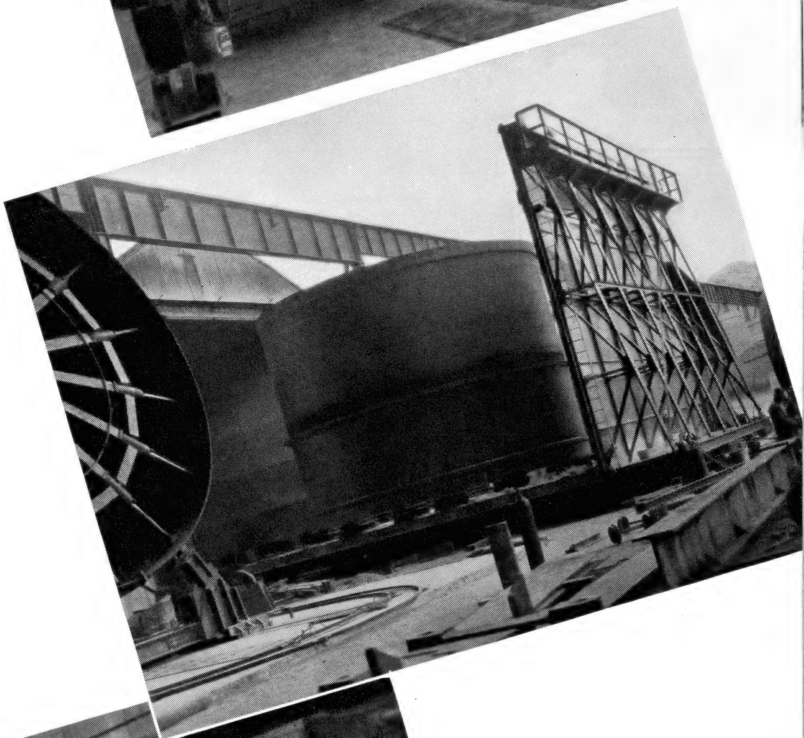
Stress Relieving after the forming and welding was accomplished in this huge oil-fired oven. The largest of its kind, the oven is 36 ft. long, 41 ft. wide and 28¼ ft. high. The front wall moves out on rails, the wall being integral with the car which carries the penstock sections into the oven. Sections are subjected to contact with hot gases circulated through the oven on a pre-determined reversed cycle in which the hot gases enter first on one side of the oven and then on the other to equalize the temperature on all sides of the section. Automatic control maintains a 1,200 deg. F. temperature for a period of time depending upon the thickness of the plate after which the temperature is reduced for a 3-hr. "soaking" period at 600 deg. F.

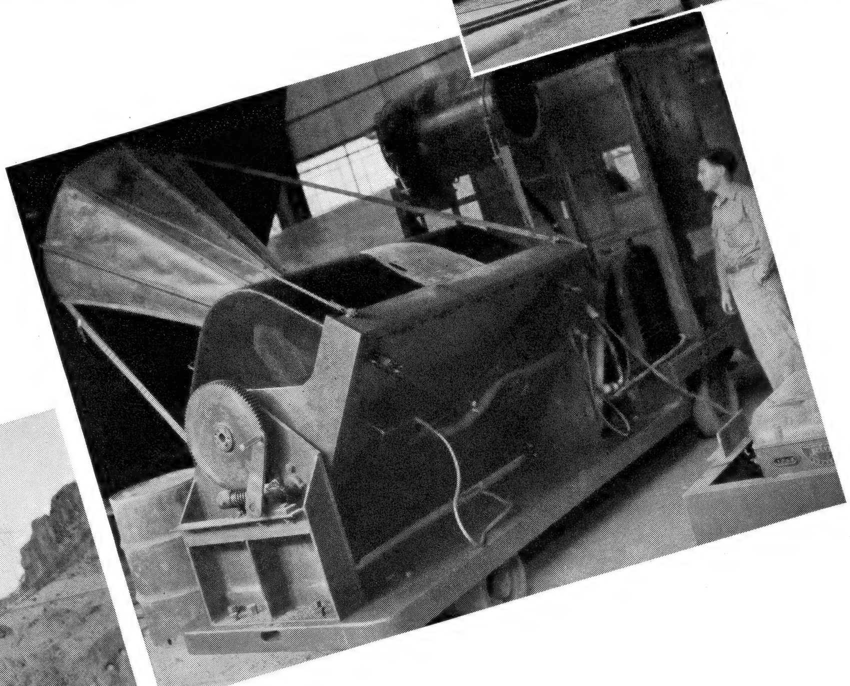
Capacity of the oven is sixteen sections of 8½-ft. penstock; four 13-ft. sections and but one 30-ft. section as shown in the illustration at the right.

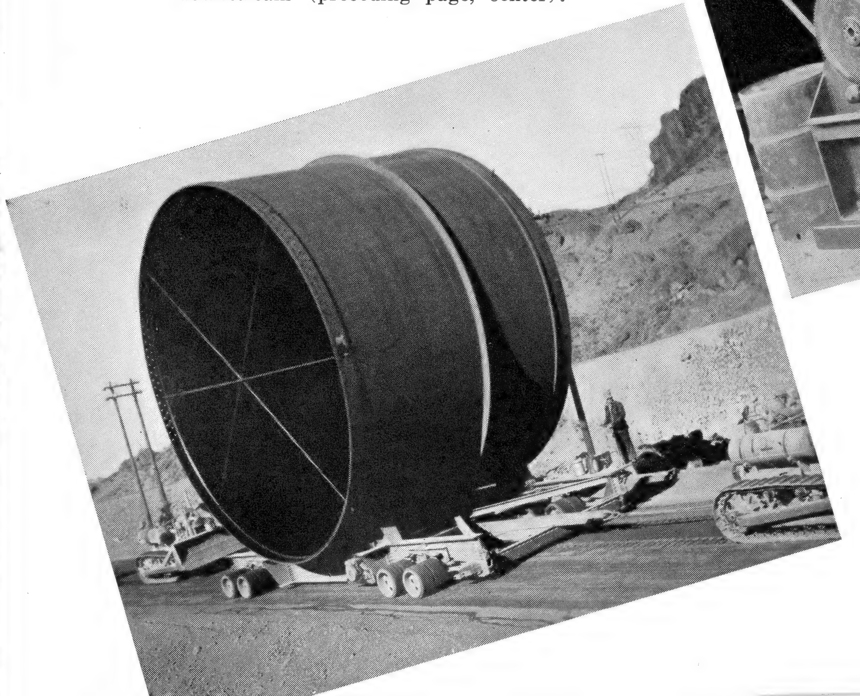
Inspection by X-Ray was required by the U. S. Bureau of Reclamation of all welds to insure homogeneous structure. This is one of the two portable 300,000-volt X-ray machines which photographed via X-rays all of the welds made in fabricating the penstocks. Machines either moved along a longitudinal weld or remained stationary while circumferential welds were rotated before its aperture. Films were developed and checked as rapidly as possible to insure approval before the section continued through the process. Where flaws were indicated, the metal was chipped away by hand and the spot re-welded manually. Sections were tested after stress-relieving, one weld specimen being taken and tested as a joint and for the strength of the weld metal itself both of which had to be as strong as the plate itself.

Installation in the tunnels was done with special dollies to move the section into position (preceding page, left). There an internal template checked shape and alignment while the section was being riveted to the adjoining section. Sections are anchored into position by means of special supports built into the rock of the diversion tunnel.

Stiffener Bars are installed for added strength at points where branch penstocks take off from the main penstock. A view in the upper penstock shows branch penstock construction as well as erection equipment further downstream (preceding page, center).

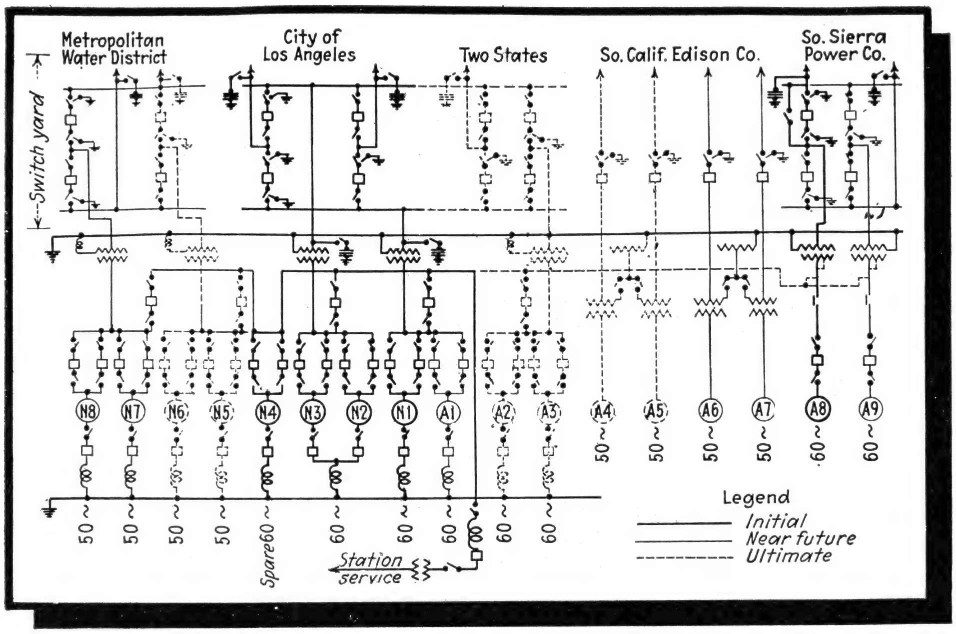






Transportation from the storage yard of the welding plant to the canyon rim was accomplished by special 16-wheeled trucks towed by tractors. The penstock sections rested in a special cradle. Equipment occupied the entire road which had to be made without the usual crown to expedite movement of these 150-ton loads.

PENSTOCKS



POWER HOUSE

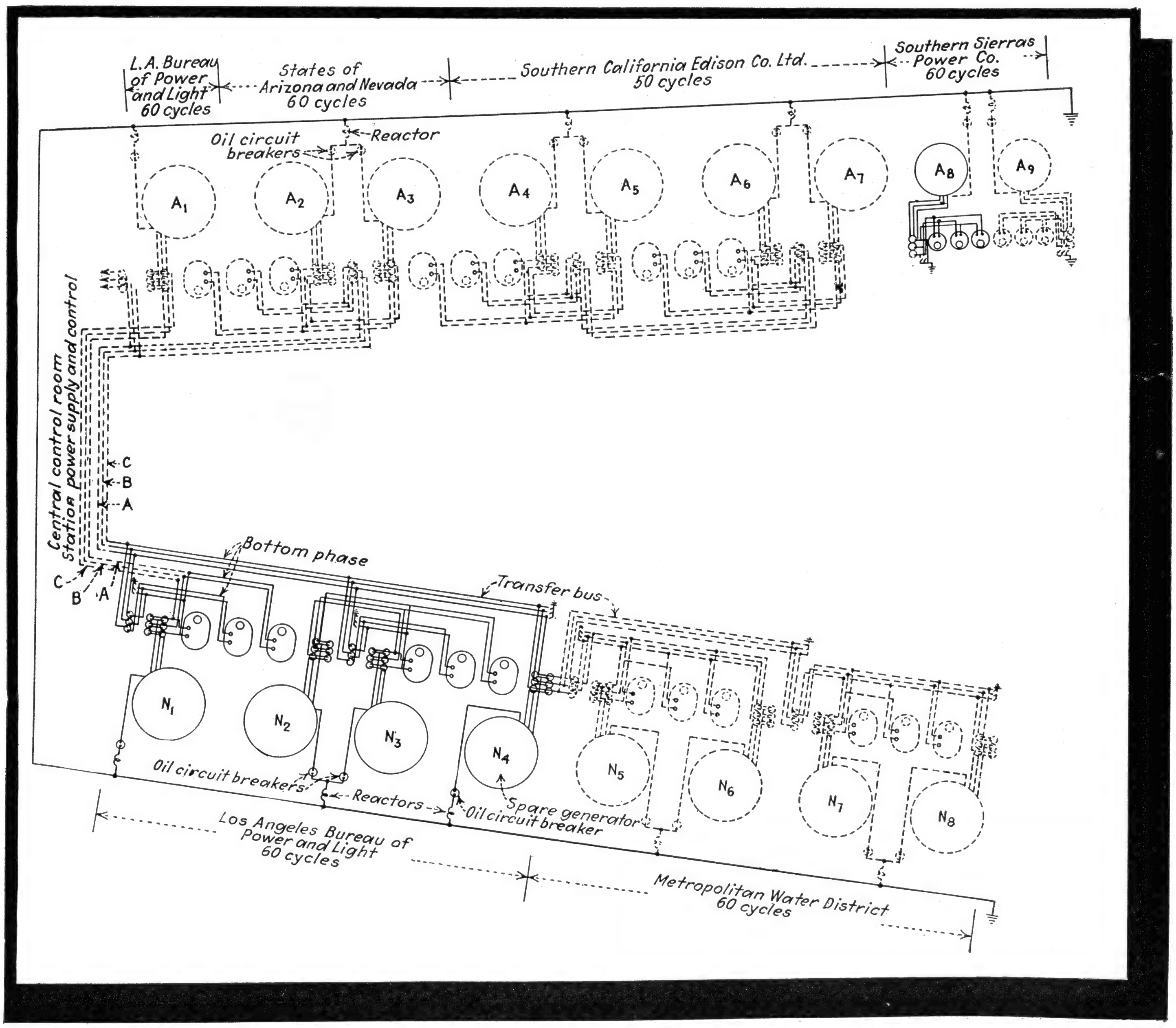
One-Line Diagram of the main circuits of Boulder Power house and switchyard. Generating units comprise:

15—82,500 kva., 16.5 kv. units
2—40,000 kva., 13.8 kv. units
2— 3,000 kva., 2.4 kv. house units

Bus arrangement is complicated by the fact that four of the main units will operate at 50 cycles and the remainder at 60 cycles. The original installation comprises four 82,500 kva. units and one 40,000 kva. unit as well as the two station service units. It will be noted that a double bus arrangement is provided both in the power house and in the switch yard.

Generator Room Layout and bus connections. In the Nevada wing there will be installed eight 82,500 kva. units, four of which are allocated to the Los Angeles Bureau of Power & Light and four to the Metropolitan Water District. In the Arizona side, one 82,500 kva. unit is allocated to the L. A. Bureau of Power and Light, one each to the states of Arizona and Nevada, four to the Southern California Edison Co., Ltd. and the two 40,000 kva. units to the Southern Sierras Power Co. With the exception of the latter two, all 60 cycle units will be connected by means of a transfer bus which extends along the Nevada wing, across the central portion of the power house (where all control and station service units are located) and in front of the three upstream units on the Arizona side.

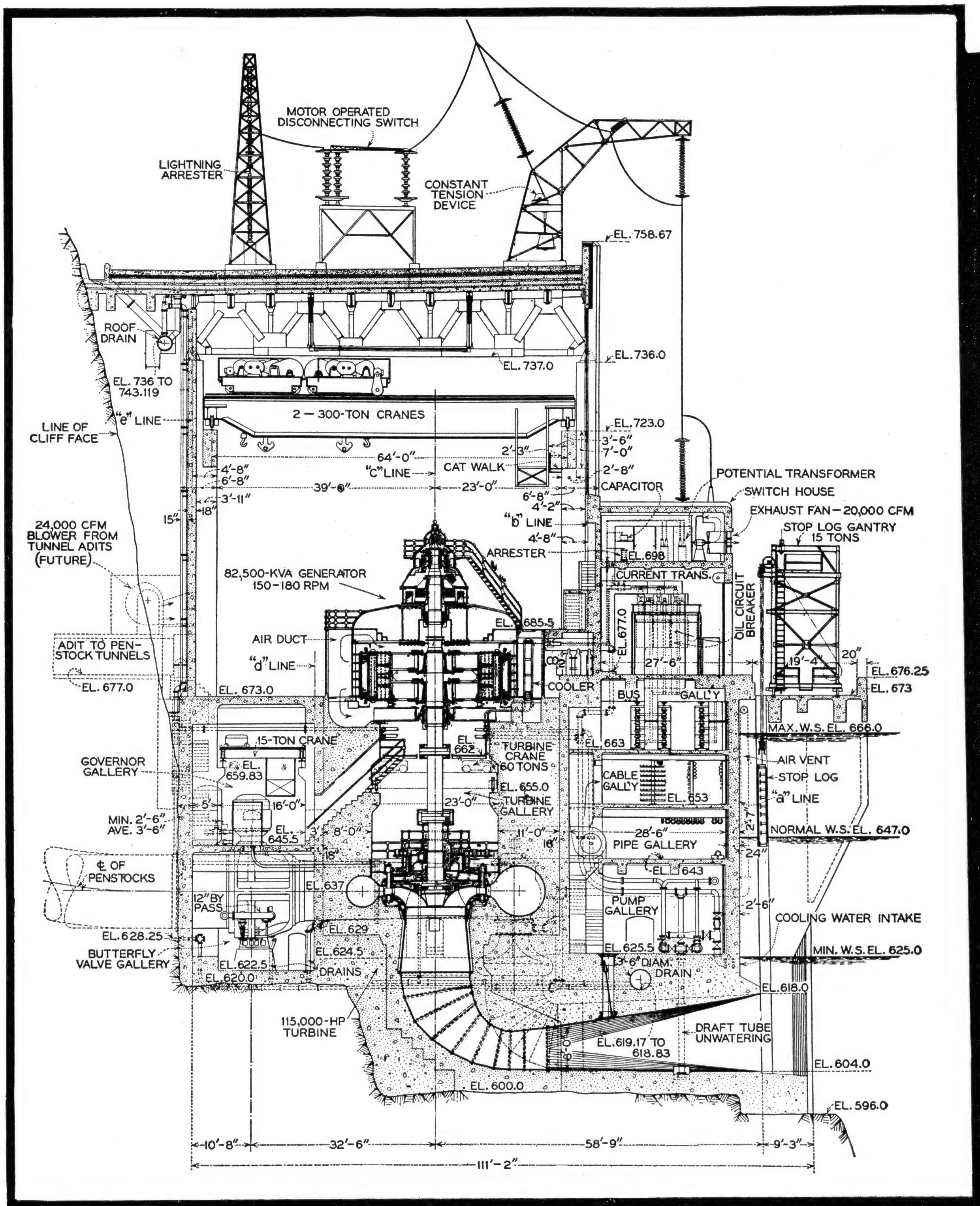
Two main generating units, through independent bus connections and metal clad switchgear units, supply one bank of 3 single-phase 16.5/ 287.5 kv. transformers, independent transmission circuits being carried up the canyon wall to the switchyard from each transformer bank.

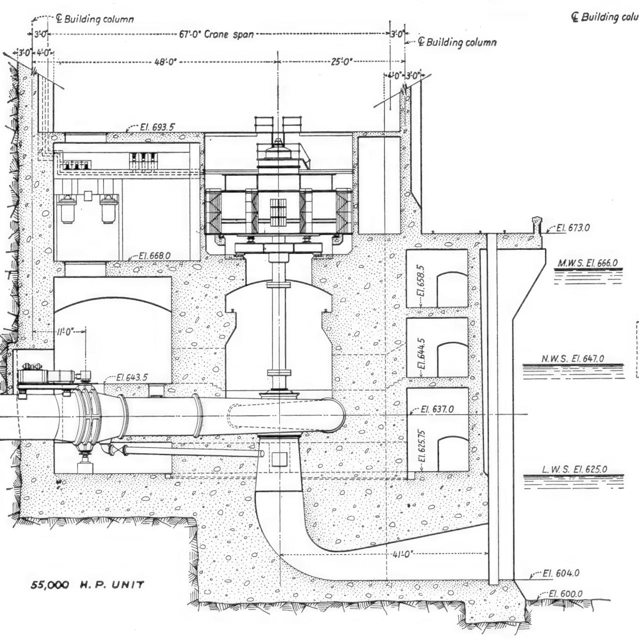


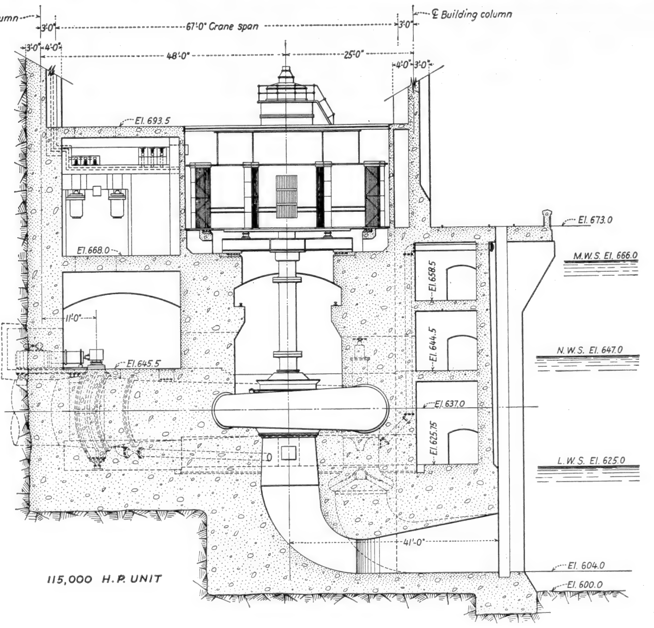
Cross Section of the power house through center line of one main generating unit. The logical layout and complete accessibility of all component parts is worthy of attention. On the canyon side of the power house are two galleries running the entire length of the wing. In the lower gallery are housed the 168-in. butterfly valves installed in the branch penstocks serving the main turbines. In the upper gallery, all the control for the hydraulic apparatus, the unit auxiliary control boards and all other control units with the exception of the generator control cubicles for electrical connections, are installed.

On the outboard or river side of each wing, other services are segregated into four galleries. The lower gallery contains sump pumps for the turbine pits. Above this is the pipe gallery where all air, water, and oil piping is grouped. Above the pipe gallery, is the cable gallery where control cables are carried in easily accessible trays and at the top the 23 kv. bus gallery to be described hereafter.

Outside of the power house proper and installed on a platform along the wing on the river side are the five switchhouses between which are the transformer bays. 287.5 kv. circuits are carried vertically to the take-off structure on the roof which consists of a tension device to prevent slack in the conductors being carried up the canyon wall and the lightning protection provided for outgoing circuits.



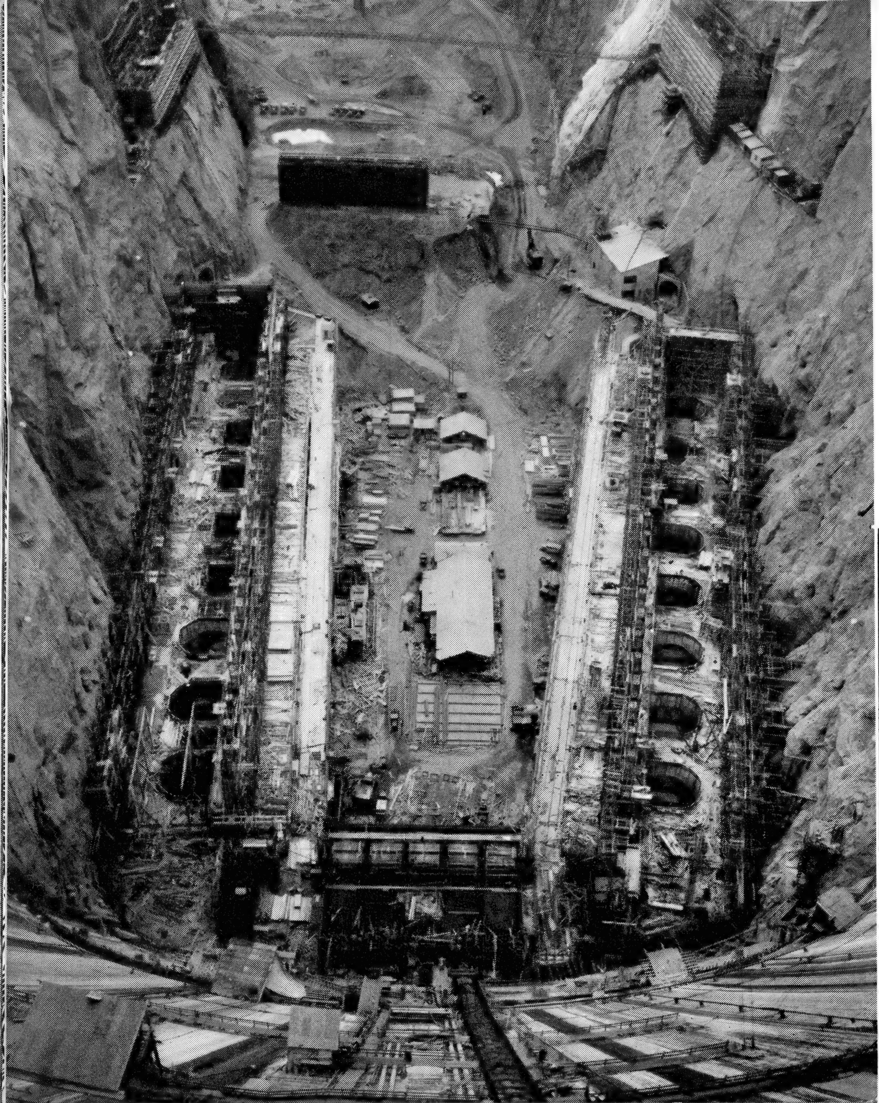




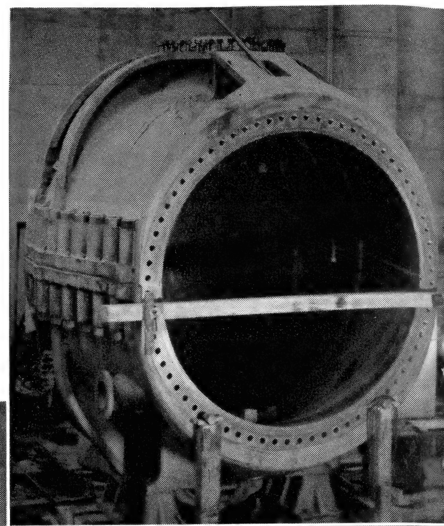
Cross Section of the 40,000 kva. unit (left) and the 82,500 kva. unit (right). The latter are the largest yet built and operate at a speed of 180 r.p.m. Each main turbine has a hydraulically operated, butterfly-type, vertically rotating shut-off valve at the inlet to the turbine casing. These valves will close against a pressure of 300 lbs. per sq. in. with an 8,000 sec. ft. flow. Two emergency by-passes are provided for each turbine.

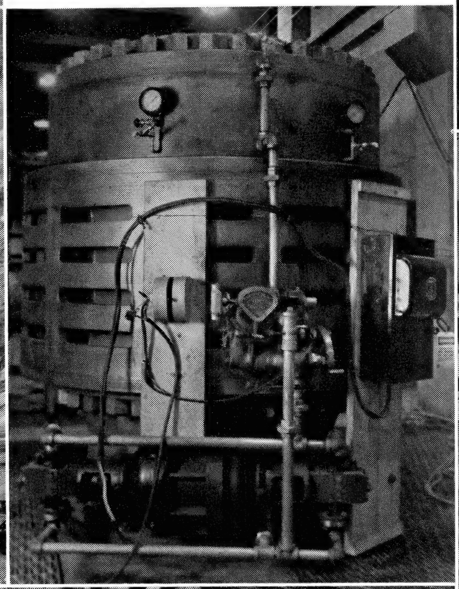
Butterfly valves normally operate with the pressure equalized on each side of the vane, the rotor being actuated by oil pressure from an individual oil pump supplying oil at 1,800 lb. per sq. in.

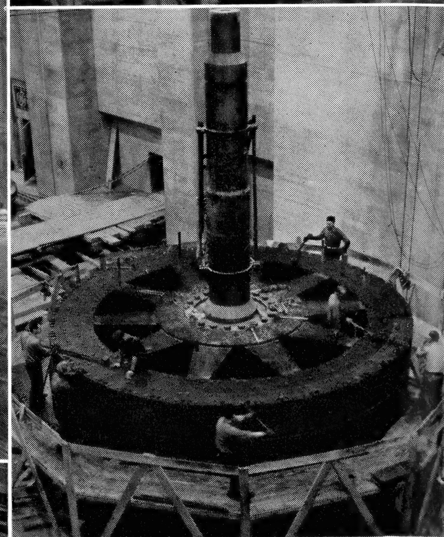
Each turbine is also provided with a pressure regulator capable of discharging 80 per cent of the full load water flow into an energy absorbing chamber.



Butterfly valves, 168-in. in diameter, are installed between the ends of the branch penstock and the turbine intake. The hydraulic operator, shown below, employs a maximum oil pressure of 1,800 lb. per sq. in. and will close the valve against a 300 lb. per sq. in. pressure with an 8,000 sec. ft. flow. Lower right—stacking laminations on a generator rotor.

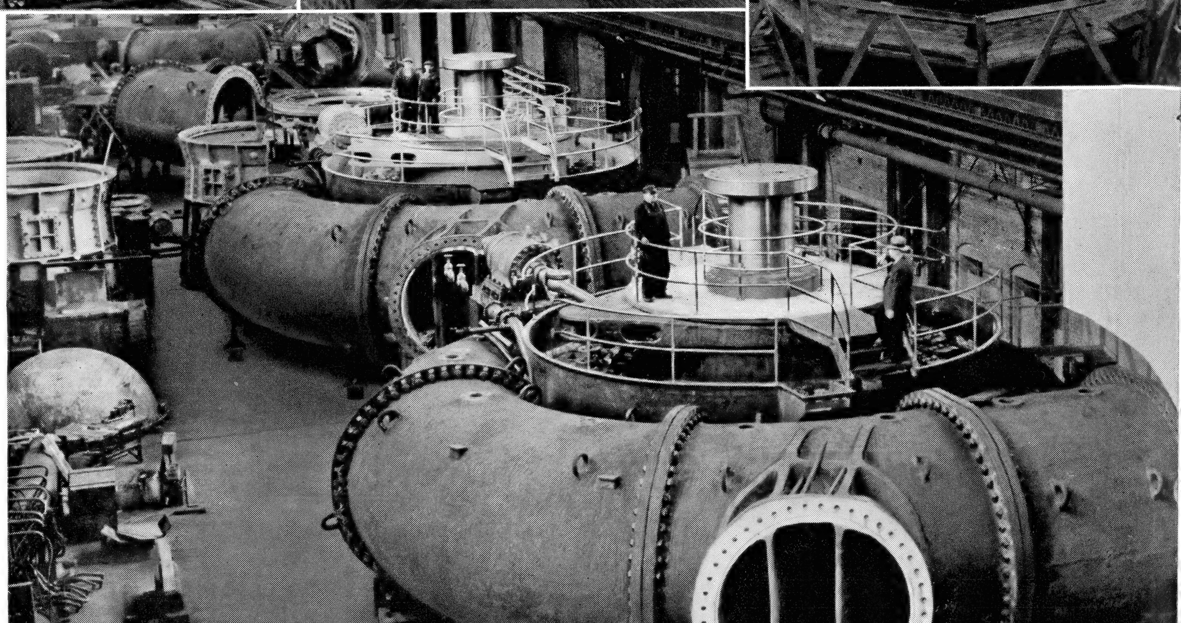


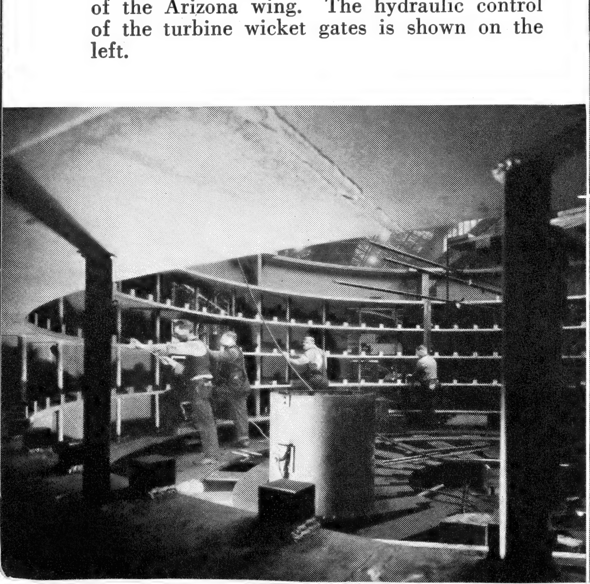


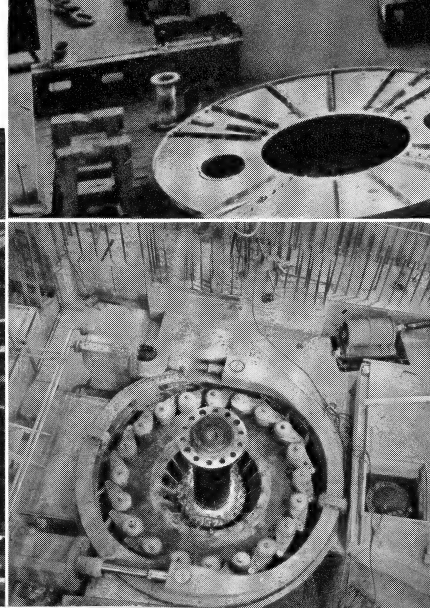


Power House during the early stages of construction. This view taken from the top of the dam clearly shows the turbine pits in which the units will be installed.

Stacking laminations in the stator of one of the 82,500-kva. main generators. The generators are 40-ft. in diameter, 32 ft. high and weigh 2,000,000 lb. Lower right—the 55,000-hp. turbine built by the Newport News Drydock and Shipbuilding Co. for driving the 40,000-kva., 257-r.p.m. Allis-Chalmers generating unit located in the downstream end of the Arizona wing. The hydraulic control of the turbine wicket gates is shown on the left.

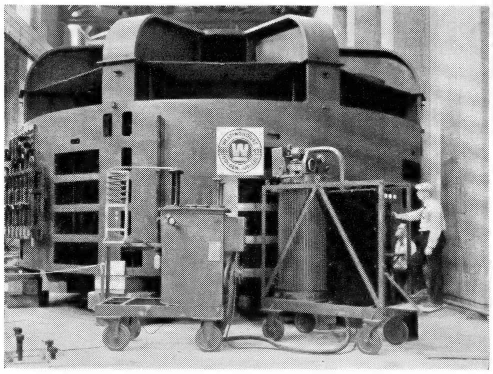






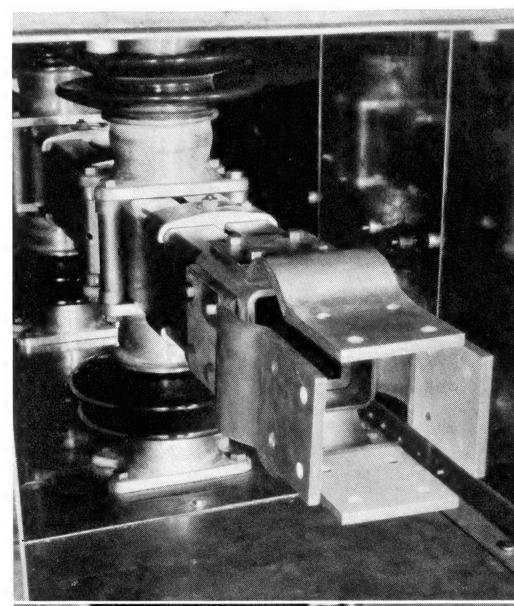
115,000-hp. Turbines set up in the Allis-Chalmers factory prior to shipment. There are four of these units installed initially. Turbines are of the single-runner vertical-shaft type with cast steel scroll cases and a single-piece cast steel runner. They will operate at 180 r.p.m. under a head varying from 360 to 590-ft., the normal head being 492 ft. Unique is the design which permits the turbine to be disassembled without disturbing the generator above.

Installing the rotor of a 82,500-kva. generator. The rotor weighs 500 tons and is handled by the two 250-ton cranes in the generating room. Stators for other units may be seen beyond this unit.

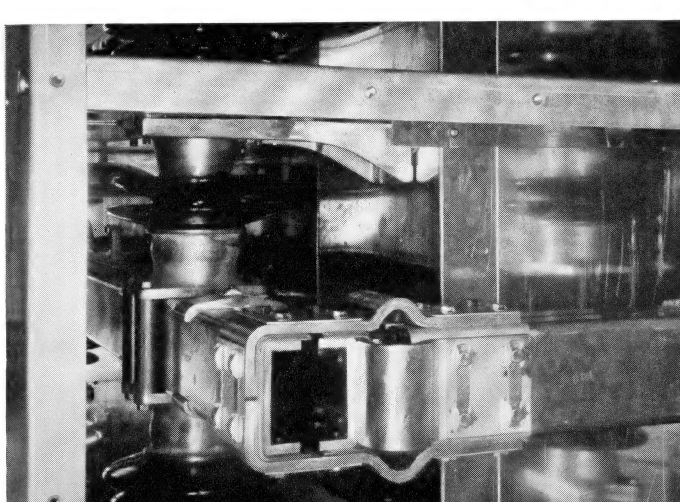


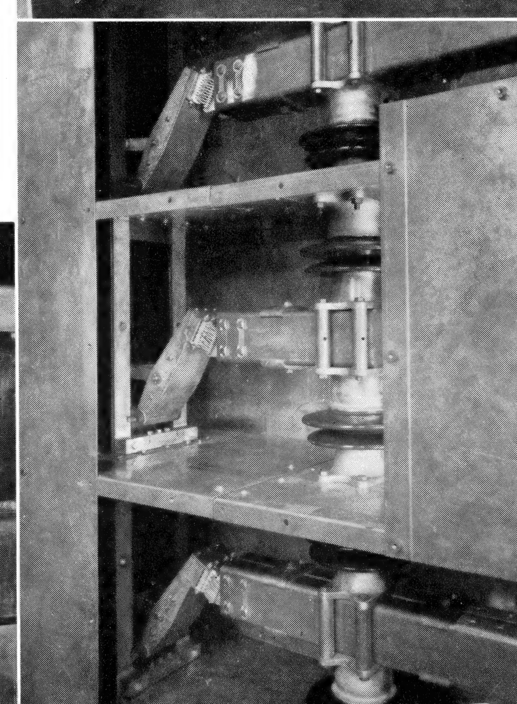
High Potential test is given a stator after assembly. The stators were shipped in segments in which laminations and coils had been installed.

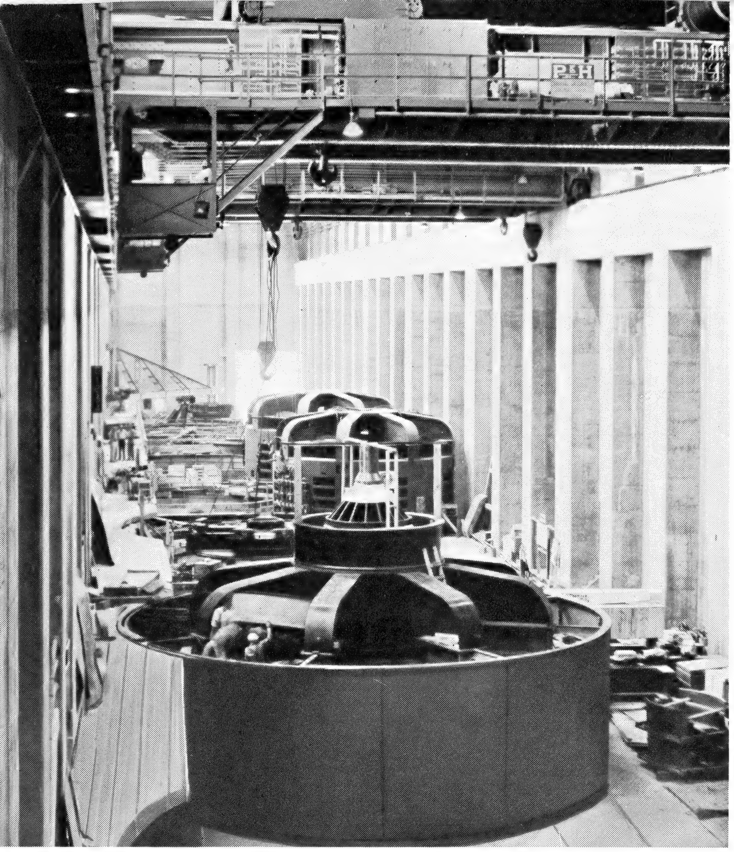
Bus Gallery extends entirely around the power house. Here are installed the connections between the generators, transformers and the generator transfer bus. The bus consists of two "U"-shaped copper channels 6-in wide assembled to form a hollow square, having a copper cross-section of 2.92 in. and rated to carry 4,000 amp. at 23-kv. Channels are clamped rigidly on 18-in. centers and supported on single-piece, porcelain insulators with non-ferrous caps and pins at 6-ft. intervals. The entire bus structure is enclosed in a copper sheet enclosure to reduce eddy current losses. Complete phase isolation is a feature of the design. The bus assembly, including all fittings, was supplied by the I-T-E Circuit Breaker Co.



Details of the bus assembly. Contact surfaces of all splices, joints and connections are silver plated. Expansion joints, consisting of laminated copper, are provided at frequent intervals. Lower left—a right-angle connector; lower right—the multi-surface grounding switch; above—an expansion joint.



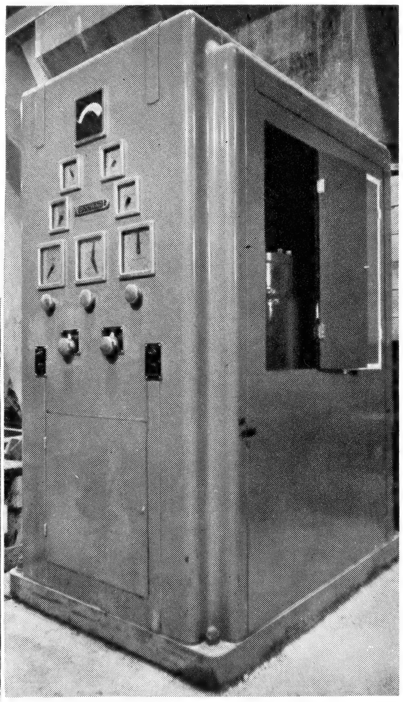


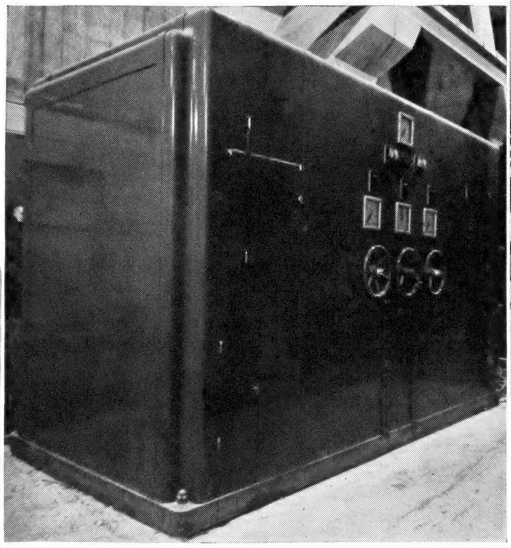


Main Generating Unit, rated 82,500 kva., 180 r.p.m., 16.5 kv., 60 cycles, and driven by a 115,000-hp. vertical reaction turbine. In the initial installation, four of these units and one 40,000-kva. unit will be installed. Two of the main units were manufactured by the Westinghouse Electric and Mfg. Co. and two by the General Electric Co. An additional two units are now on order. Except for their huge size, the generators are of conventional design in which a thrust bearing at the top of the unit carries the entire weight of the rotor and runner. Two guide bearings also are provided. Each unit has a direct connected main and pilot exciter (not installed when this view was taken).

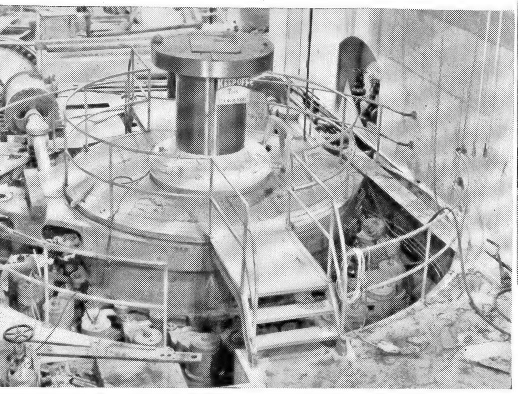
An extra large moment of inertia of 110 million lb.-ft. squared is incorporated in the rotor to provide better stability for the long transmission system. Reactance also is low, the transient reactance being 21 per cent with a short circuit ratio of 2.4, these machines being equivalent to a normal rating of 125,000 kva.

Air operated brakes are provided to bring the rotor to rest and are so arranged to act as jacks for raising the rotor up off the thrust bearing to facilitate inspection and maintenance.



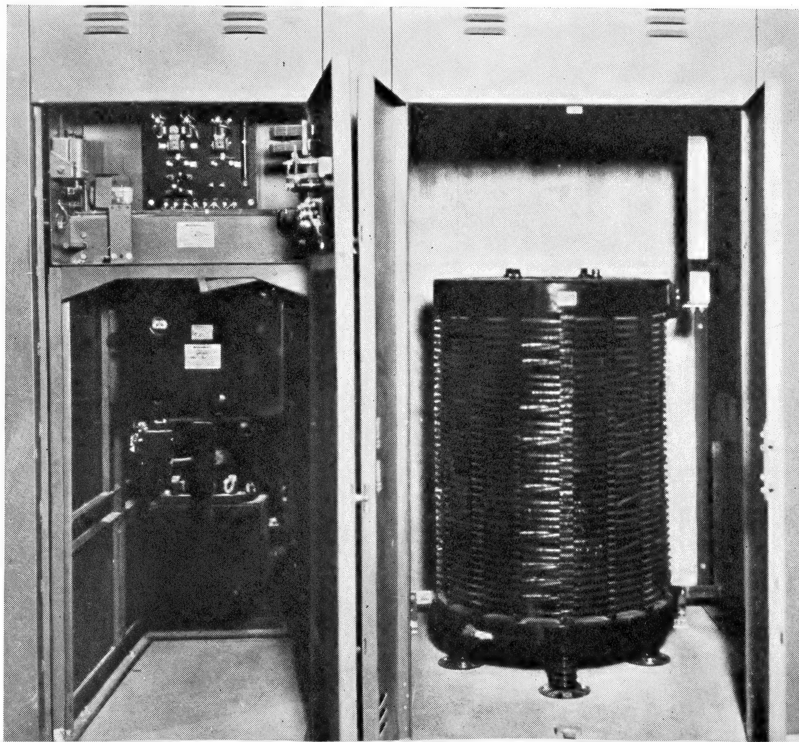


115,000-hp. Turbine installed and ready for connection to the shaft extension of the generator. A crane in the turbine gallery permits disassembly from the side in the space shown here by removing shaft extension and without disturbing the generator assembly.

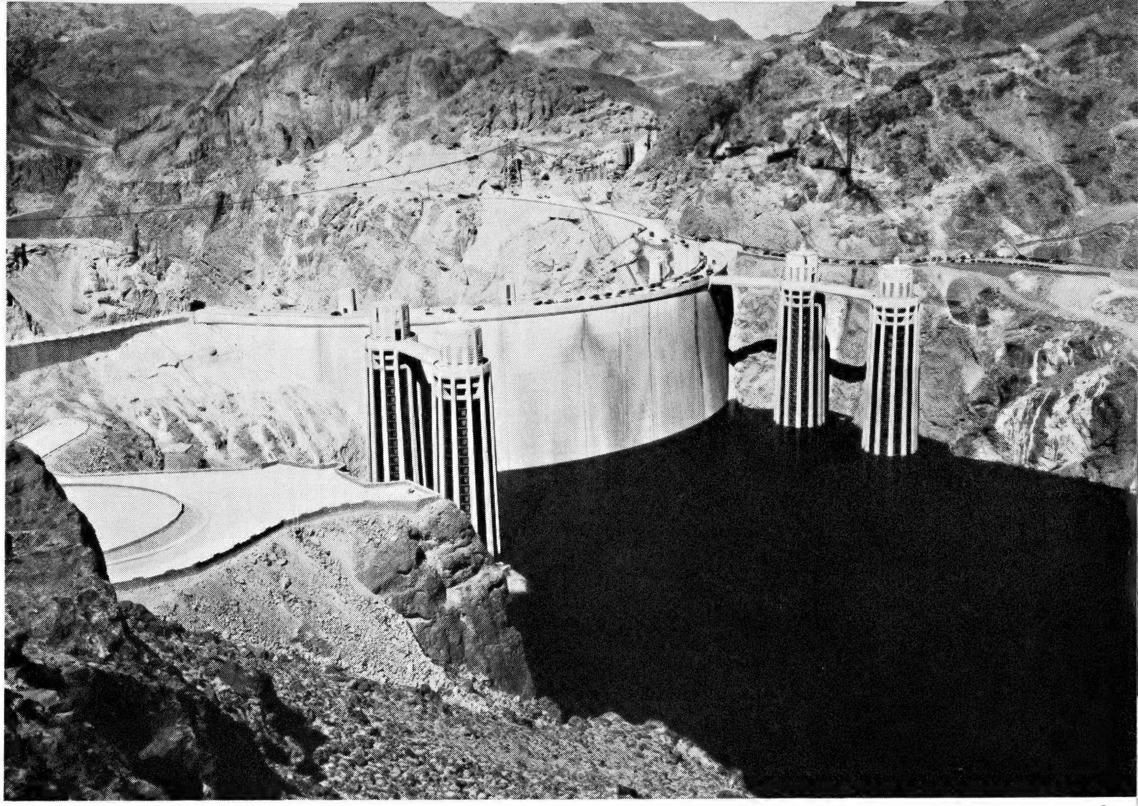


Neutral Reactors are connected in the neutral of each generating unit to limit ground fault current in the neutral to 10,000 amp. This shows the method of recessing the reactor and associated circuit breaker in the wall of the power on the cable gallery level.

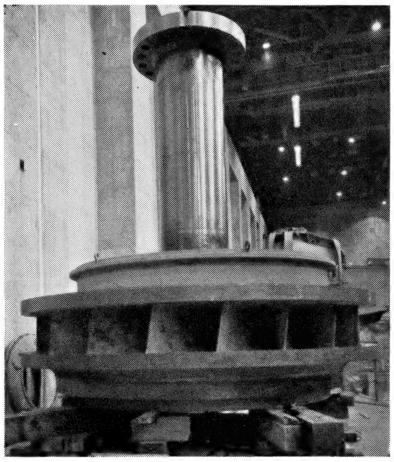
Governor mechanism, built by the Woodward Governor Co., is capable of opening or closing the turbine gates in 5 seconds under full head. Governors are of the oil-pressure, relay valve actuator type controlling the gate position through oil-operated "servo" motors. Speed response of 0.01 per cent is obtained through a small permanent-magnet 7½-cycle generator mounted on top of the main unit driving a 7½-cycle synchronous motor, flyball mechanism. Pre-set load control, frequency control and automatic synchronizing are provided, the latter being obtained through an automatic thermionic device installed on the switchboard which controls turbine speed through the speed adjusting motor on the governor.

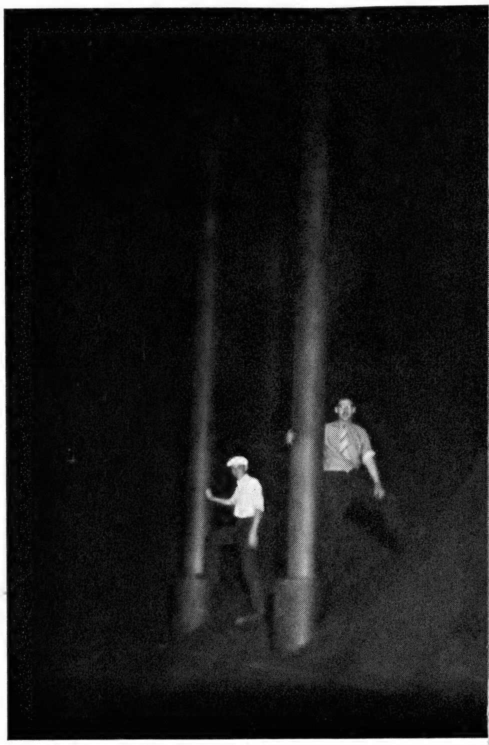


Intake Towers are essentially vertical reinforced concrete cylinders each with twelve radial buttresses supporting the trashracks. Each tower has two cylindrical gates each having a vertical lift of 9 ft., one being located at the base of the tower and the other half way up. Intake towers are 403 ft. high, 82 ft. in diameter at the base and 64 ft. in diameter at the top.



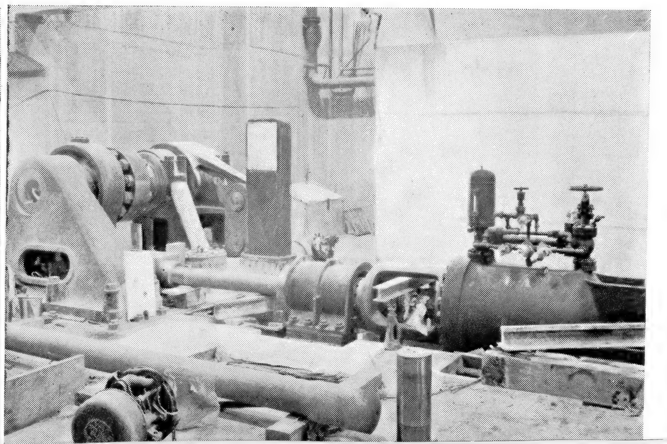
Cast Steel Runner for a 115,000-hp. turbine awaiting installation in its turbine.





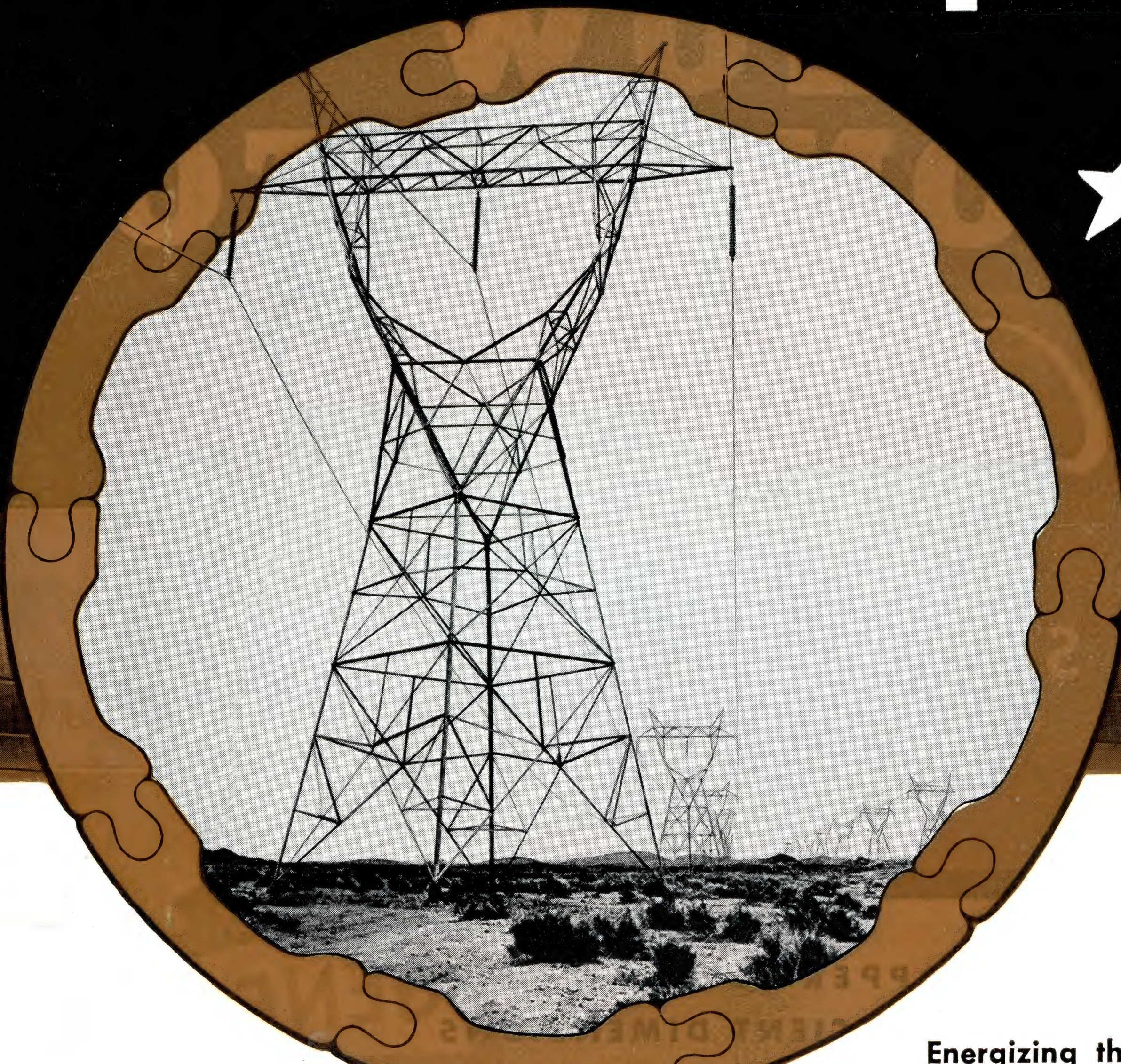
Penstock in the lower diversion tunnel is 30 ft. in diameter and, at points where the 13-ft. branch penstocks take off, is reinforced with these huge stiffener bars.

How the Inside of a 115,000-hp. turbine looks. This view was taken during the machining of the wearing rings and looks back into the penstock through the stationary vanes.



Pressure Regulator for the main unit is a huge relief valve capable of discharging 80 per cent of the total full-load flow. By means of a mechanical linkage to the governing mechanism controlling the turbine wicket gates, the pressure regulator acts to divert the flow in emergencies through an energy absorbing chamber into the tailrace.

The Eyes of the Industry are upon it



Energizing the 287,000 volt Boulder Dam — Los Angeles line completes the outstanding achievement in power transmission . . . Never was a line more thoroughly engineered . . . Never was an overhead conductor given more searching preliminary tests of mechanical and electrical characteristics . . . Never were test results more conclusive . . . Type HH Cable was chosen to carry the load for the "8th Wonder of the World".

GENERAL CABLE CORPORATION

Sales Offices: ATLANTA · BOSTON BUFFALO · CHICAGO · CLEVELAND DALLAS · DETROIT · LOS ANGELES · NEW YORK · PHILADELPHIA · ROME PITTSBURGH · SAN FRANCISCO · ST. LOUIS · SEATTLE · WASHINGTON, D. C.

GENERAL CABLE

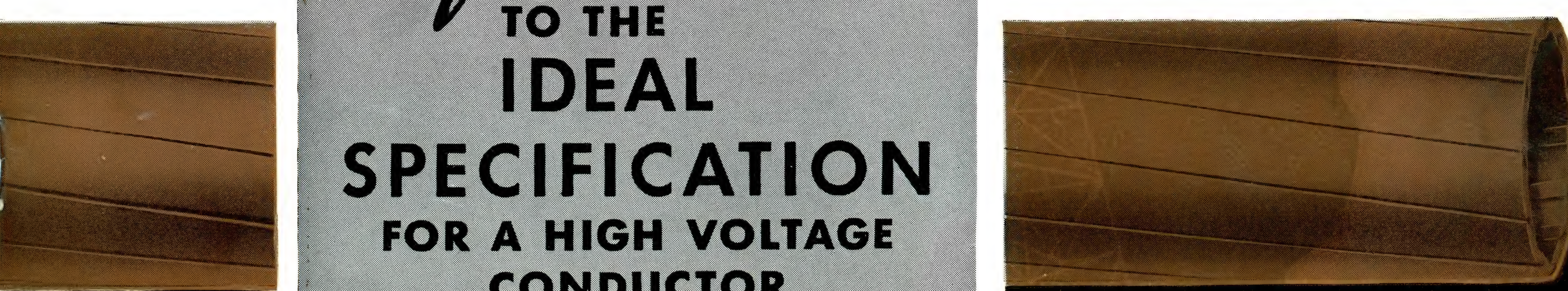
TYPE HH

HOLLOW CONDUCTOR

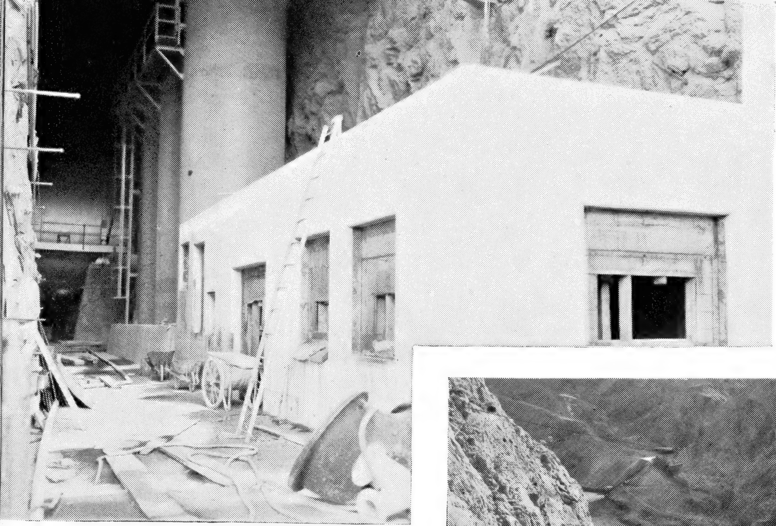
Conforms **IN EVERY DETAIL TO THE**

IDEAL SPECIFICATION

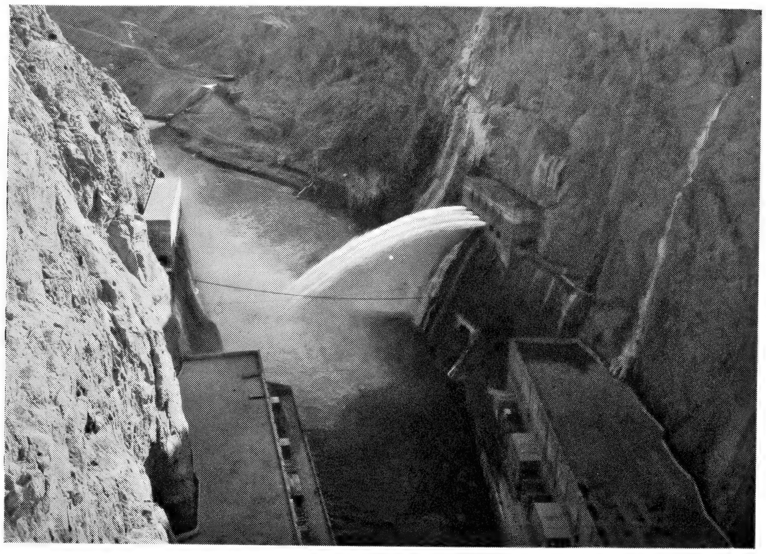
FOR A HIGH VOLTAGE CONDUCTOR



1. ALL COPPER CONSTRUCTION
2. 100% EFFICIENT DIMENSIONS
3. SMOOTH SURFACE CONFIGURATION
4. MINIMUM CORONA LOSS . . . . . .
5. MAXIMUM WEIGHT SAVING . . . .
6. MINIMUM REACTANCE . . . .
7. INHERENTLY NON-VIBRATING
8. TIGHTLY INTERLOCKED SEGMENTS
9. SIMPLICITY OF FITTINGS . . . . . .
10. ECONOMICAL ERECTION . . . . . .



Oil Purifying and storage plant for the units of Nevada wing is located in this building in the upper adit at the point shown by the arrow in the photograph below.



Watermaster's meter board is vital to the operation of the plant. A large number of water distributing agencies rely upon the flow of the river below the power house and the watermaster must coordinate power and water demands to the best efficiency.

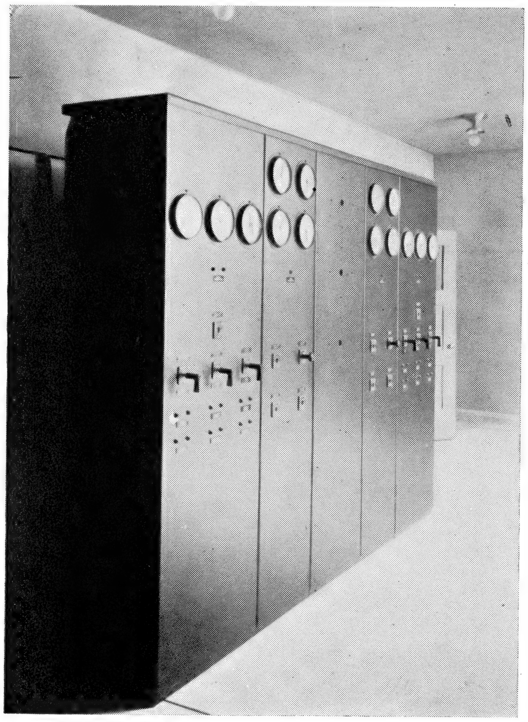
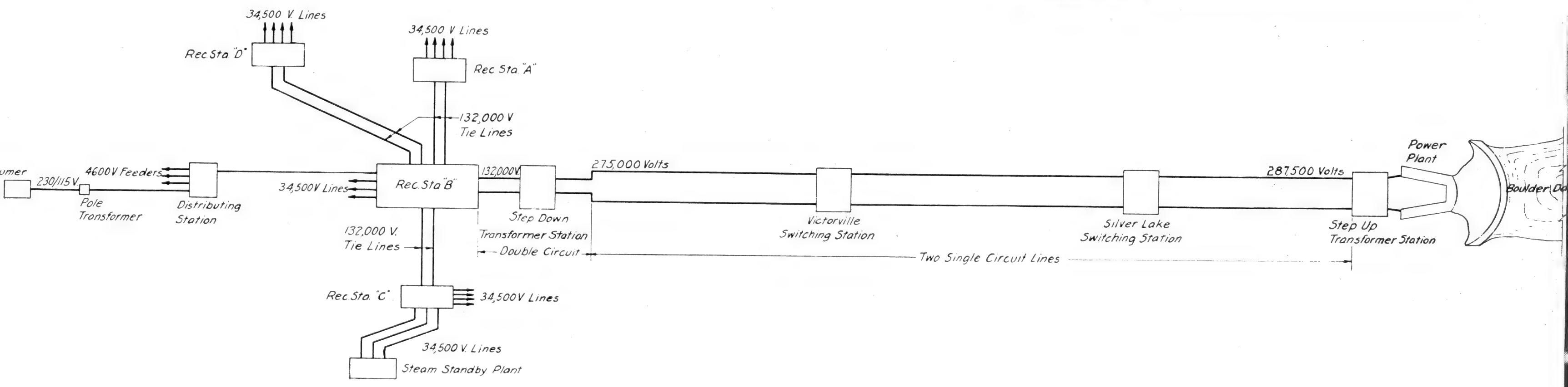
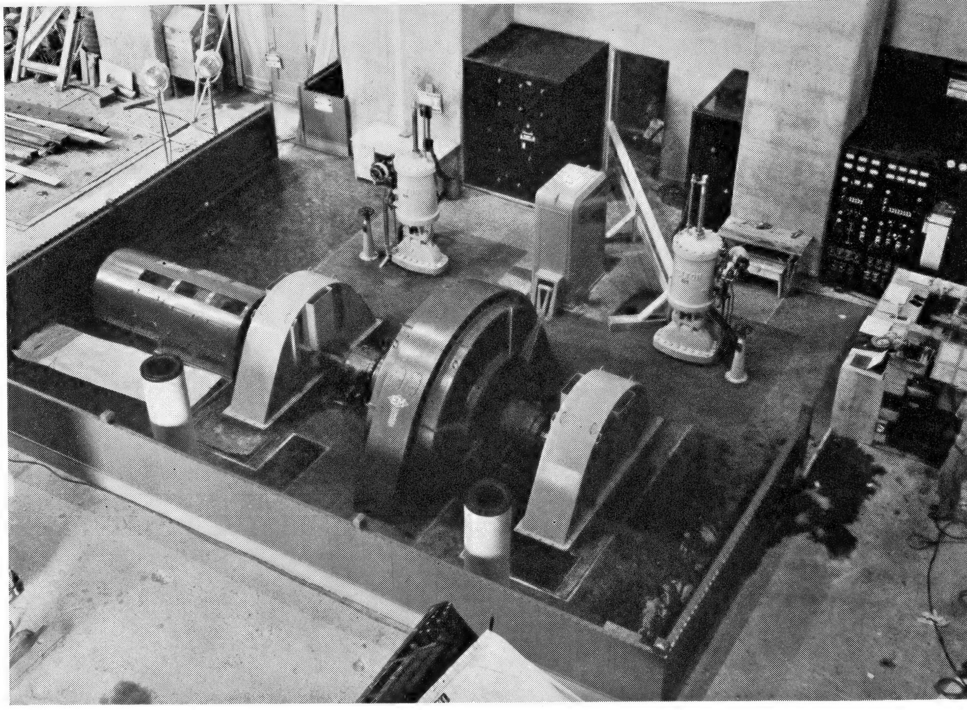


Diagram of the circuits by which the first power from the project will reach consumers. A detailed description of the transmission and distribution is included on succeeding pages.

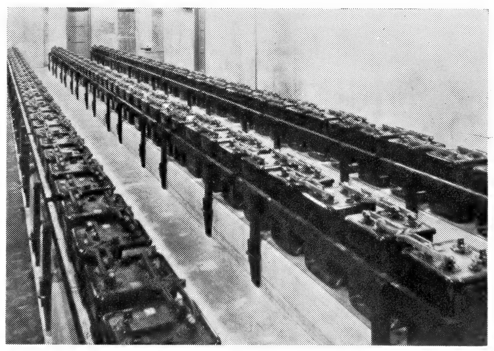


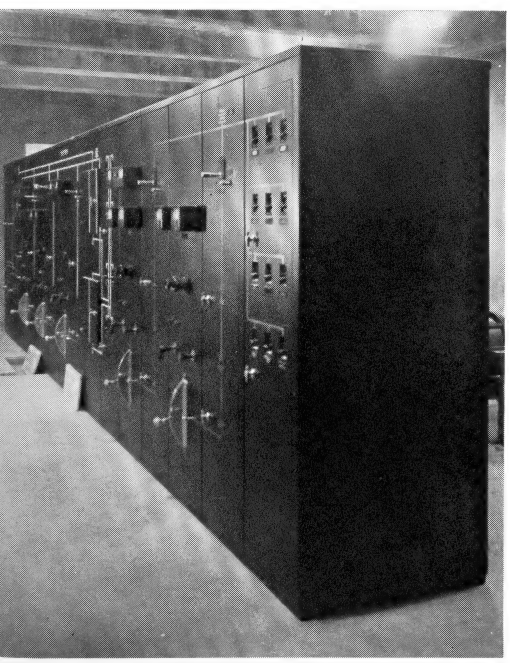
STATION POWER

A House Generator rated 3,000 kva. and driven by a double Pelton impulse turbine, is installed at the upstream end of each wing of the power house. Governors and control cubicles are located against the inner wall of the main generating room on the operating floor. These units are connected by a 36-in. diameter penstock which is carried through the central portion of the powerhouse, the ends of the penstock being tapped into a branch penstock, serving the upstream main units on either side of the power house, making it possible to supply house turbine from either wing. House generators serve the main 2,400-volt station power bus housed in the metal-clad switchgear cubicle shown below. As a supplementary source of station power a 16.5/2.4-kv. bank of transformers, energized from the main powerhouse bus, also feeds the station power bus.

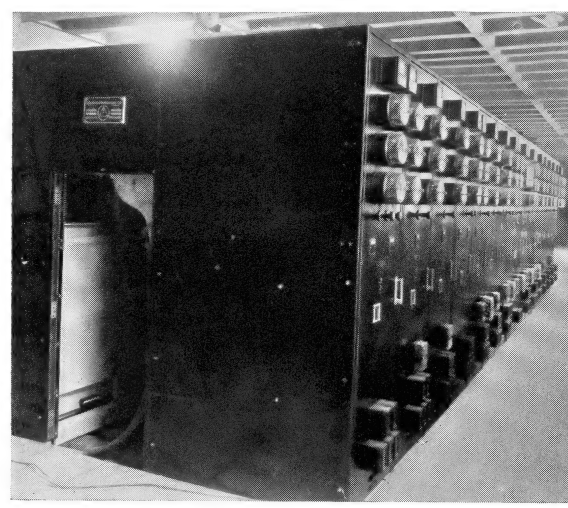


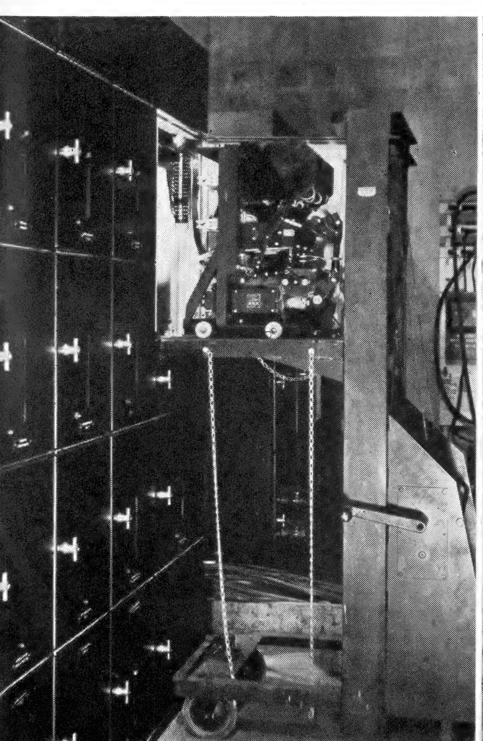
2,400-volt Switchgear cubicles of the metal-clad vertical-lift, draw-out type, serve the station service power feeders. This switchboard, built by the Delta-Star Elect. Co., supplies 2,400-volt power to the various transformer banks which reduce the voltage to 460 volts for all station power requirements or to 110-220 volts for lighting circuits. Because the project is so large it was more economical to locate station power transformer banks near the station service load centers and carry 2.4-kv. feeders to these points rather than attempt to centralize the source of 460-volt power. This switchgear is controlled from the miniature control switchboard in the main control room of the power house (shown on the next page).





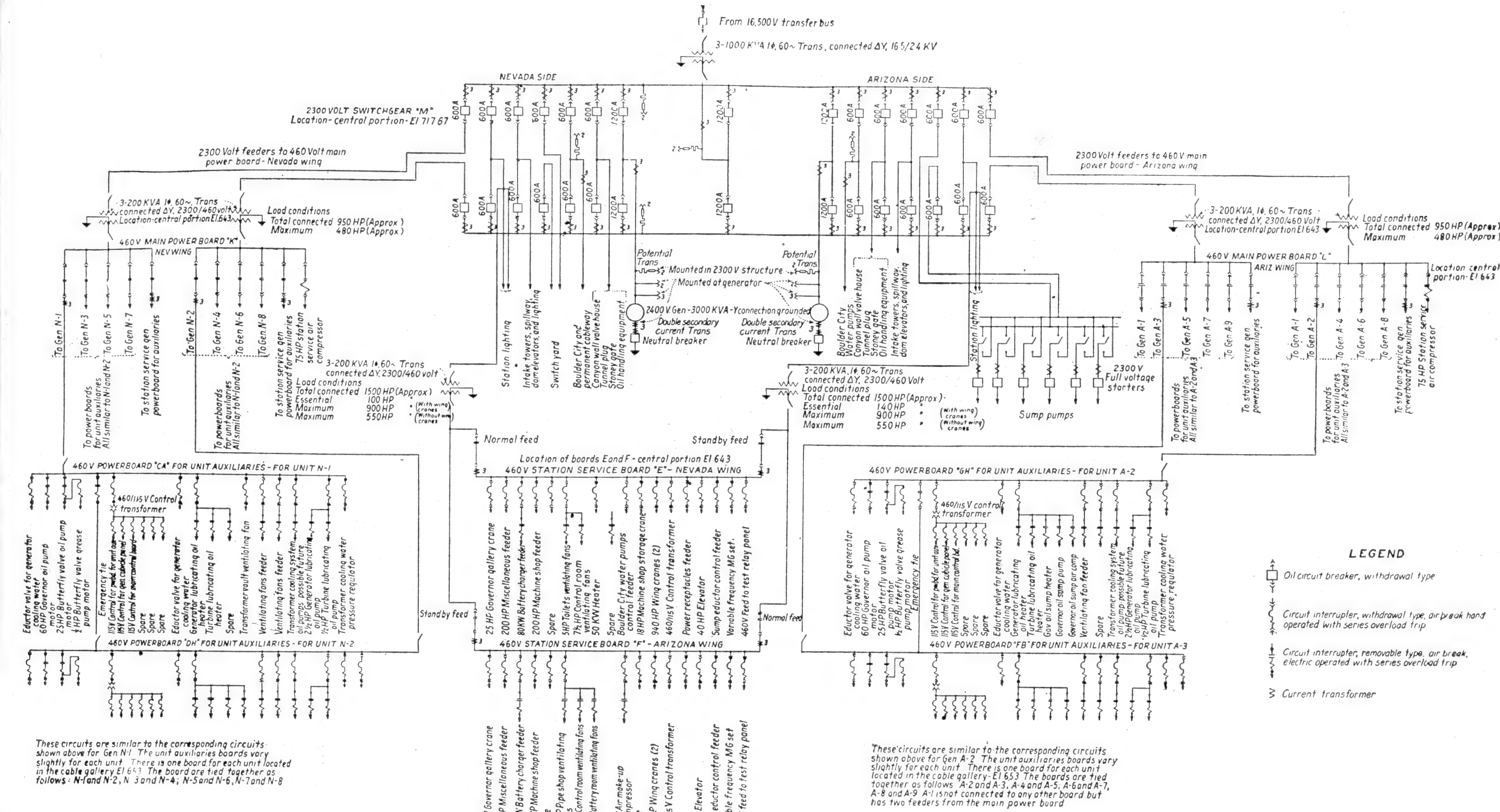
Direct Current for the power house is supplied from two sources. The first source consists of two 120-cell Exide storage batteries (above) together with three 550-volt motor-generator sets bussed through the switchboard so that one set floats on the line with each battery and one acts as a spare. The second source consists of a 60-cell battery with two similarly arranged 125-volt m.g. sets. All switch control in the plant is energized from the direct current power sources, 250 volt circuits supplying standby motor-operated auxiliaries and switch, breaker, contactor operating mechanisms. 125-volt d. c. is used for remote control through auxiliary relays and for indication. This view (left) shows the main d. c. switchboard, built by the Square D Co., from which all d. c. circuits emanate.



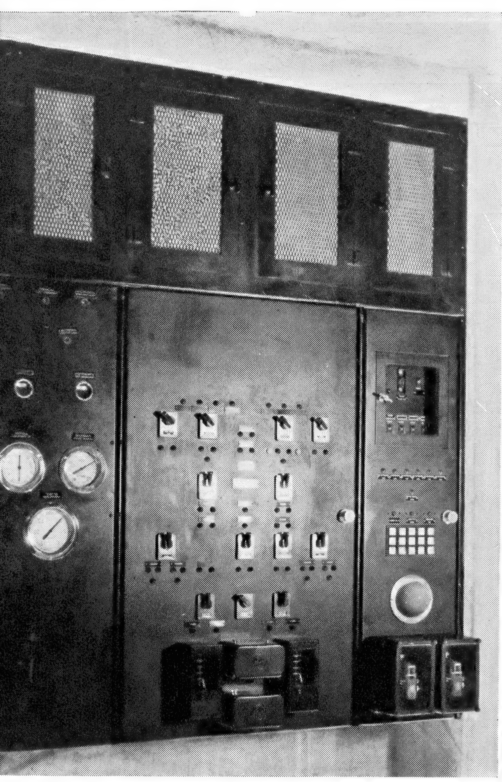


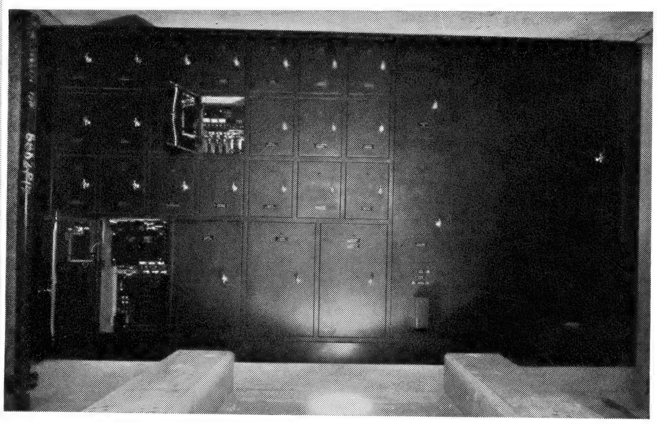
Station Service Load is divided into two groups, all served from four switchboards similar to this one. One group comprises all of the equipment essential to operation of the main units such as oil and lubricating pumps, valve operating motors, etc. These circuits are supplied through four banks of transformers, feeding the 460-volt power distribution switchboards. One bank serves the unit auxiliary power panels for each of the even numbered main generating units in one wing; a second, the odd numbered units in that wing, and the remaining two banks serve the generating units in the other wing in a similar manner. Cross connections on the 460-volt buses permit power to be obtained from either bank serving one wing. The second group serves non-essential equipment, such as cranes, machine tools, etc., power being obtained from a transformer bank supplying each wing.

Compactness is a feature of these Roller-Smith switchboards (left). A total of four switchboards, two for the essential auxiliaries in each wing and two for non-essential auxiliaries in each wing, are installed in the central portion of the power house. Air circuit breakers, operated by direct current, are removable from their panel positions by means of the truck shown on the left.



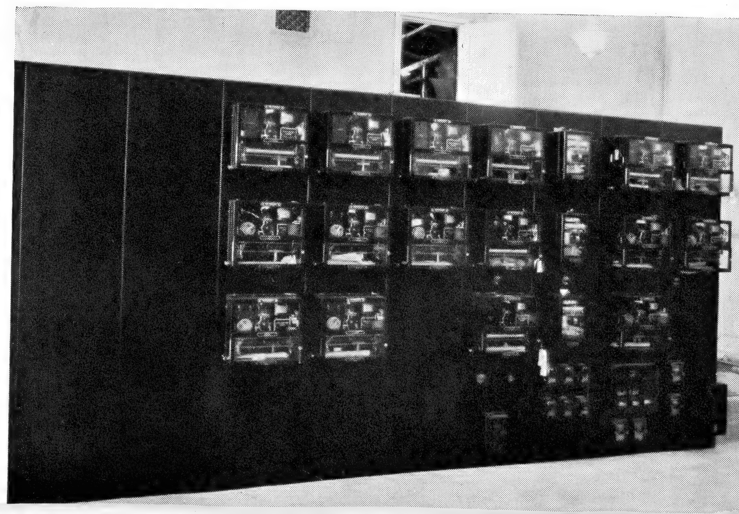
One-Line Diagram of station power circuits. Continuity of operation for all equipment in the power house is obtained by so arranging the power supply for each main unit that it can operate independently of all other units. To this end each unit is equipped with an individual 460-volt auxiliary power panel served by an individual feeder from one of the 460-volt power distribution boards shown on the preceding page. In addition all essential equipment is dual drive, normally from a. c., but from d. c. in emergencies. All governor oil pumps, valve motors, etc., have both a d. c. and an a. c. motor drive.

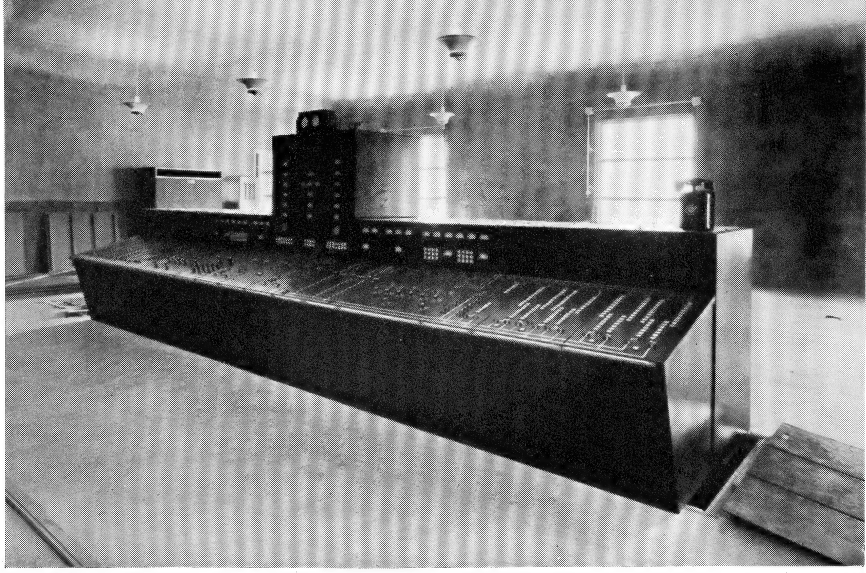


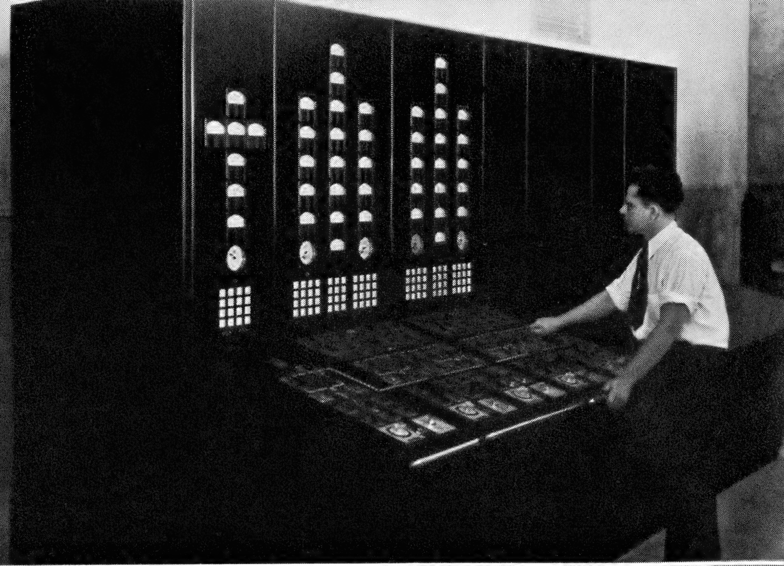


The Power Output of each main unit is recorded on this totalizing meter board equipped with Leeds and Northrup recording meters. This board is installed adjacent to the control switchboards in the main control room on the upper floor of the central portion of the power house.

Power for unit auxiliaries is obtained through this power panel (center), there being one such switchboard for each main generating unit installed in the wall of the cable gallery. These power panels contain motor starting switches and magnetic contactors controlling oil pumps, motor-operated valves, blowers and all other equipment essential to the operation of the main unit. Control for these units is centralized on the control board (shown above) which is installed in the governor gallery. Starting operations are interlocked in a sequence so that it is impossible to bring a unit up to speed without having all auxiliaries operating. All of the unit auxiliary power and control panels were supplied by the Cutler-Hammer Co. under specifications of the USBR.

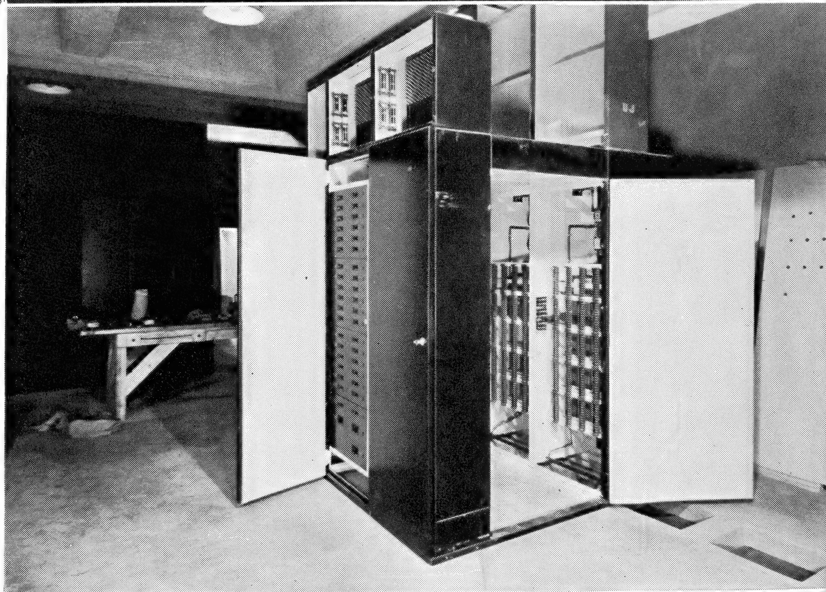






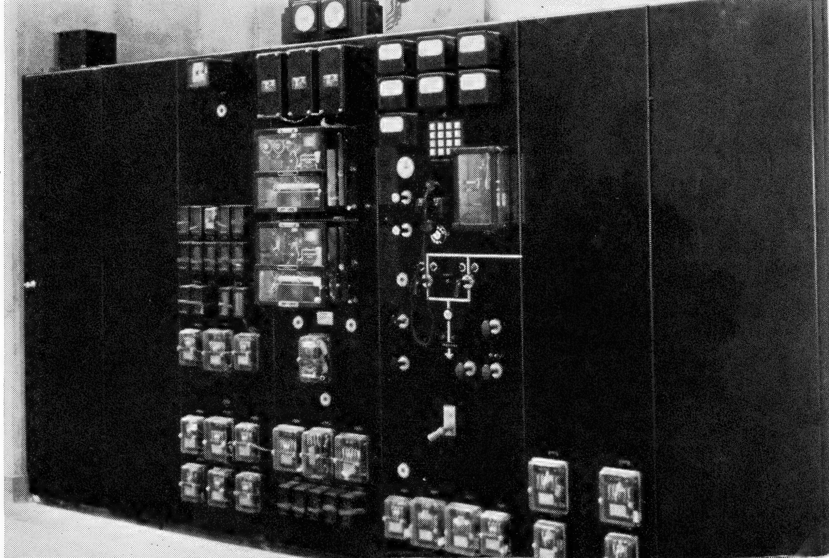
Centralized Control for all equipment in the power house is possible through miniature switchboards of the benchboard type installed on the upper floor of the central portion of the power house. Miniature switches and meters provide the operator with all of the essential information and equipment necessary for switching, loading and synchronizing each unit. Compactness is indicated by the view in the upper right-hand corner which shows all of the meters, instruments and control switches necessary for operation of four main units.

Above is the miniature benchboard controlling all unit auxiliaries in the power house. Here is centralized the switching control for 2,300 and 460-volt switchboards described on the preceding pages. A feature of both the unit auxiliary and main control switchboards is the annunciator system consisting of a series of apertures mounted in the face of the panel through which an alarm light shows when abnormal operating conditions occur on any piece of apparatus. Each annunciator panel is approximately 1½-in. square and the ten or twelve required for each main unit are grouped together for convenient observation by the operator. These groups are visible at the base of the vertical panels of the miniature switchboards.



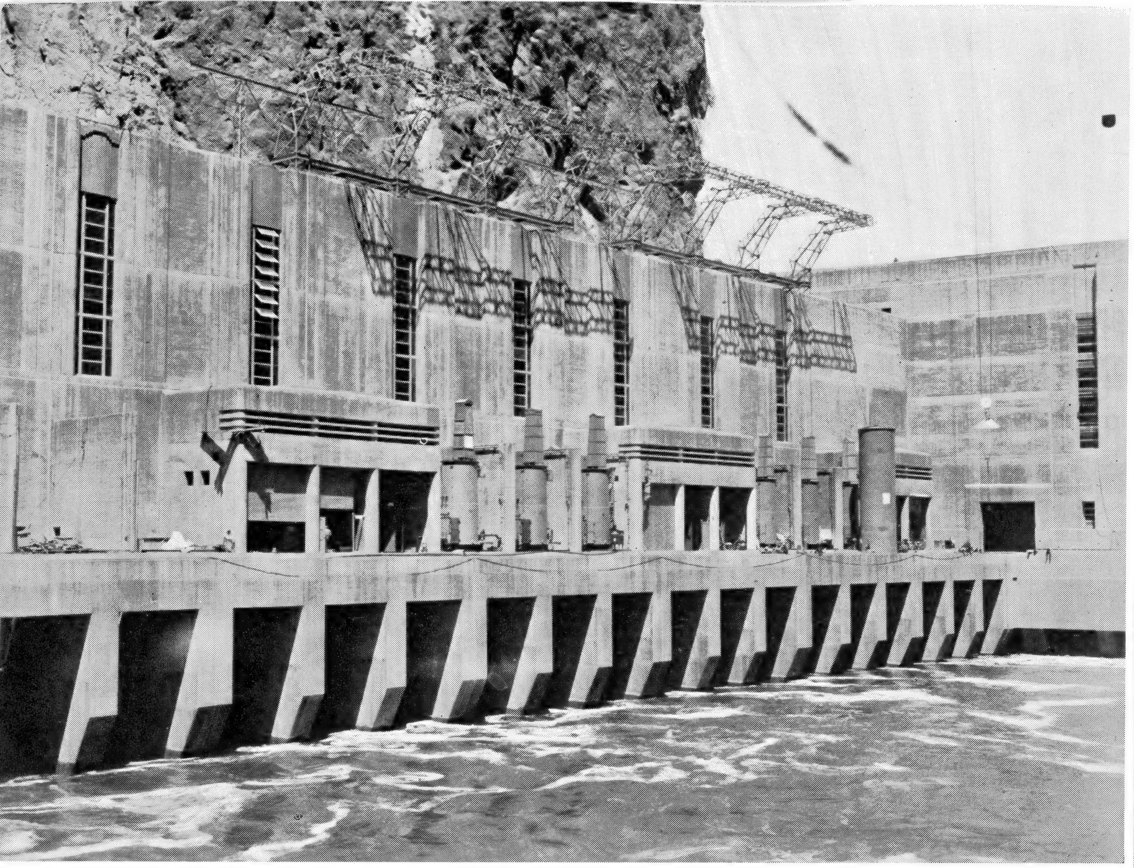
Arrangement of control circuits parallels the layout of the wings shown in the vertical cross-section of the power house on page 13. Immediately below the main control room is the cable terminal room where control cables from the wings and central portion terminate in cabinets located directly under the miniature switchboards and meter boards in the room above. At the left is shown one of the terminal cabinets with the doors open to show the terminal strips which facilitate wiring and maintenance. Connections to the control and meter boards are carried up through the ceiling in metal housings.

Cable Racking Room located directly below the terminal room consists of vertical tiers of Transite trays in which the control cables from all portions of the plant are grouped and carried to their proper positions under their respective terminal boards on the floor above. Lead covered, multi-conductor control cables extend from this room down risers to the cable galleries along each wing where they are supported on trays similar to those shown here.

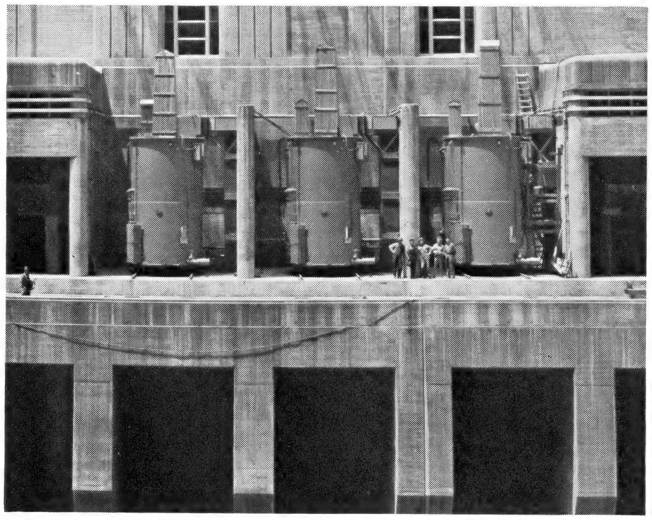


Generator Control Cubicles are installed against the river wall on the operators' gallery overlooking the main generating room adjacent to the units they serve. Hereon are all the control switches for synchronizing, loading and operating the unit. This control is duplicated in its essentials on the miniature benchboard panels in the main control room (see above). However, the operator on the generating floor can either operate the unit from this point via telephone instructions from the main control room or transfer control to that point by means of a switch on this panel. The sequence of operations is such that the operators in the turbine gallery must start the unit auxiliaries and bring the turbine up to speed before the electrical control can function to synchronize the unit and place it on the line.

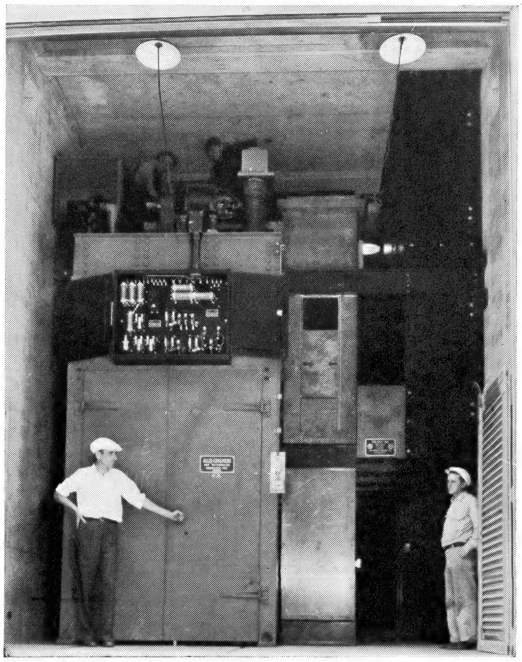
Through Leeds and Northrup load and frequency control equipment, any unit can be placed on base load, proportionate load or frequency control automatically. Frequency is corrected automatically when deviations exceed 0.01 cycles.



Generators are connected through the 4000-amp., 23-kv. double bus to the main transformer banks. Because of the limited space in the canyon for outgoing circuits, two generators serve one bank of three 16.5/287-kv., 55,000 kva single phase, 60-cycle transformers. The necessary primary switchgear for each generating unit is installed in switchhouses built on the platform outside the main wall of the power house as shown in the accompanying photograph. Between each switch house are three transformer bays in which are installed the transformers supplied from adjacent generating units.



Transformer Bay showing the three 55,000 kva. transformers which step the 16.5-kv. primary voltage up to 287-kv. for transmission. Physically these units, built by General Electric, are the largest in the world, as well as operating at the highest voltage used commercially. They weigh 385,000 lb. (of which 150,000 lb. is oil) and are 32 ft. high. The design is the circular-coil, non-resonating type with a shielded high voltage winding. A water curtain for fire protection is provided in each transformer bay.

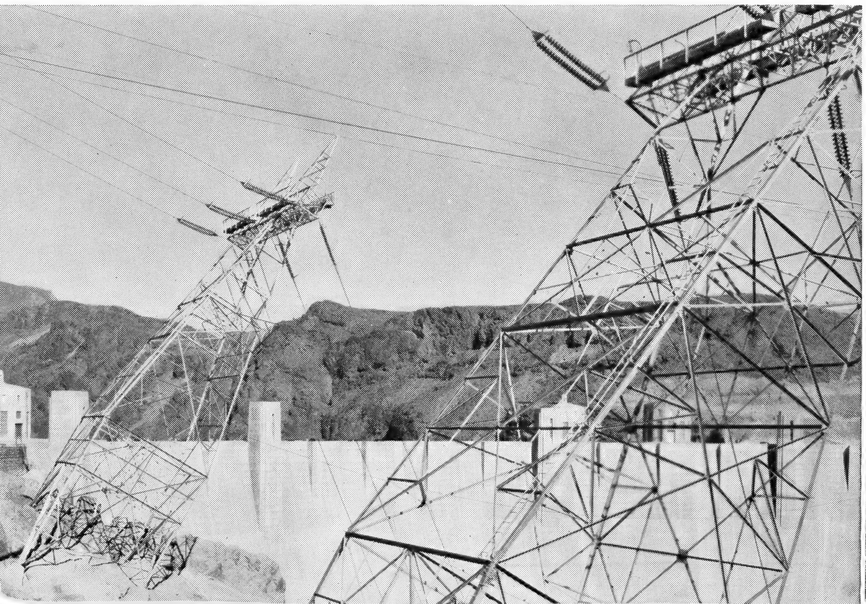


Metalclad Switchgear units for the 23-kv. bus switching arrangement were built by the Allis-Chalmers Mfg. Co. The bus connections to the metalclad units are essentially a continuation of the bus structure described on page 15. The bus riser and connection here is shown at the right.

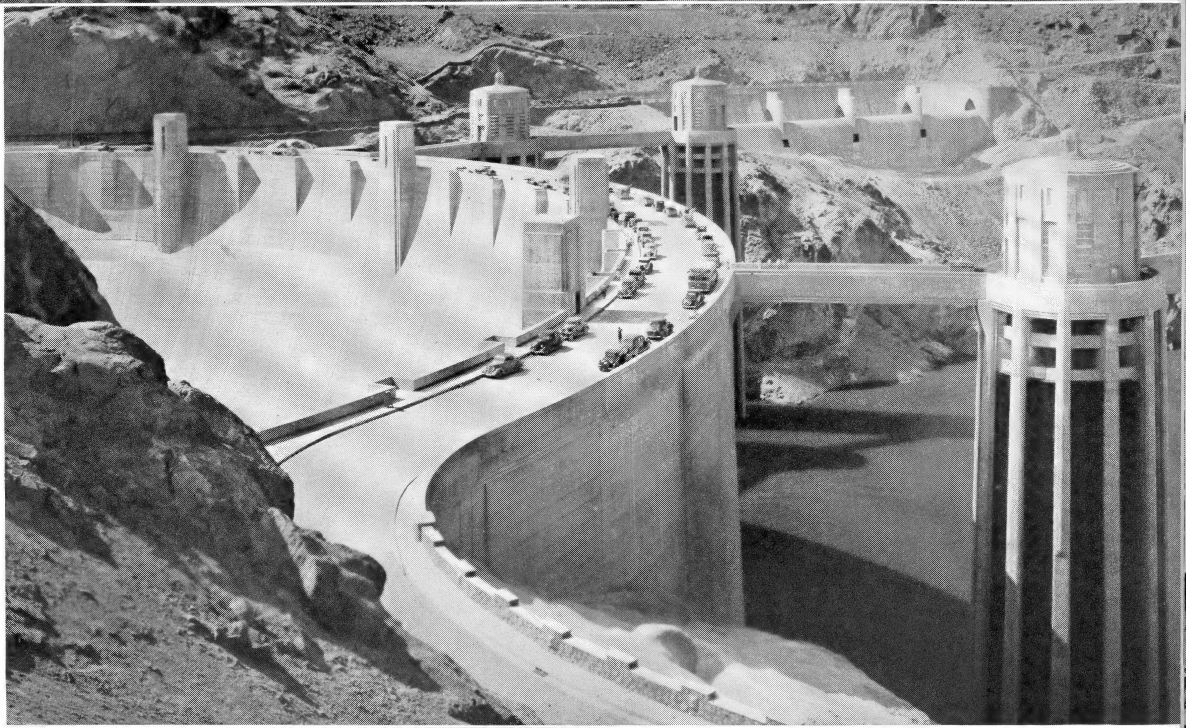
Takeoff Structures for transmission circuits departed from the conventional practice because the circuits leave the power house in a vertical instead of horizontal plane. On the roof of the power house is mounted an overhanging steel rack (see upper left) which supports conductors from the high voltage bushing of the transformer banks immediately below.

From this point the conductors run vertically to the overhanging transmission towers installed at almost a 45-deg. angle on the rim of the canyon and from there on conventional towers to the 287-kv. switchyard.

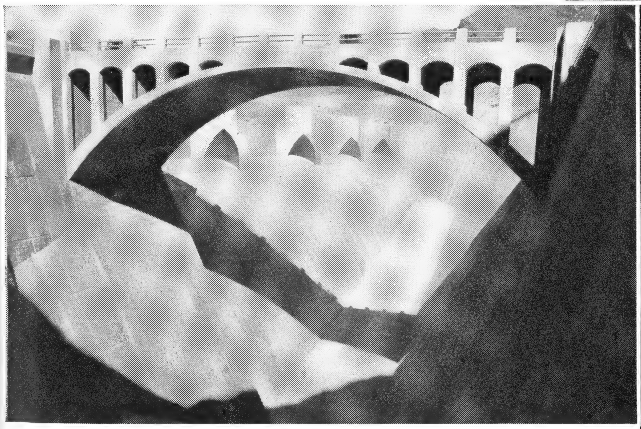
On the Roof Structure of the station a 3-phase lightning arrestor for each circuit, and the 3-pole 287-kv. disconnecting switch necessary to isolate it from the line, are installed. Also installed is an interesting counterweight device for each conductor which maintains sufficient tension in the vertical rise of the cable to keep it from swinging either into the canyon wall or adjacent conductors. The counterweight (see below) consists of a weight suspended from the conductor over a double sheave to keep it from twisting, the necessary insulation in the suspension being provided by a double string of insulators.



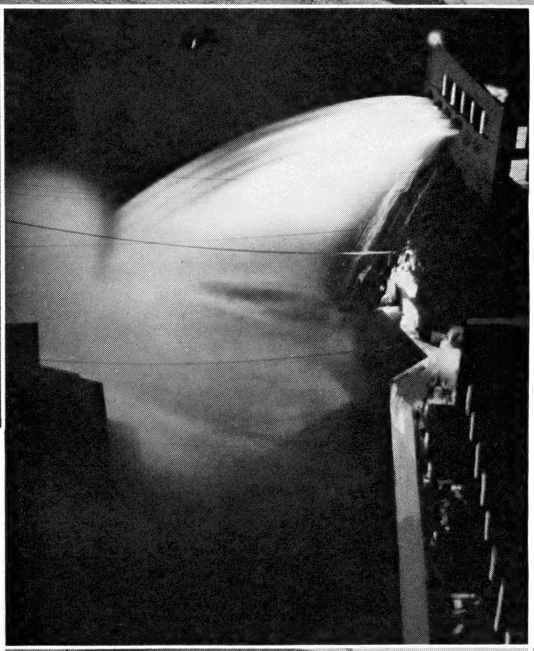
Lake Mead, the 115-mile body of water formed behind Boulder Dam, was named in honor of Elwood Mead, former Commissioner of the United States Bureau of Reclamation, who died during the construction of his Bureau's greatest project.



General View of the dam taken from the Arizona side showing the roadway across the dam which provides a highway link between Las Vegas, Nevada, and Kingman, Ariz., and eliminates the need for a ferry across the river.

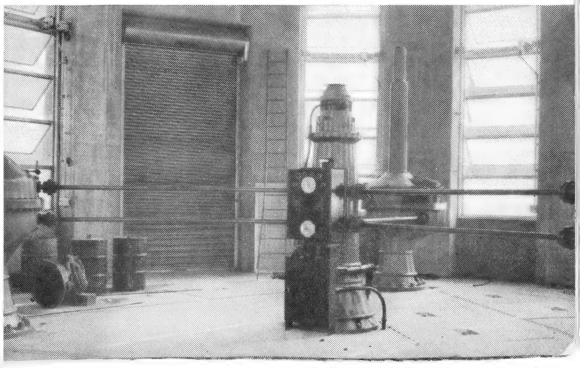


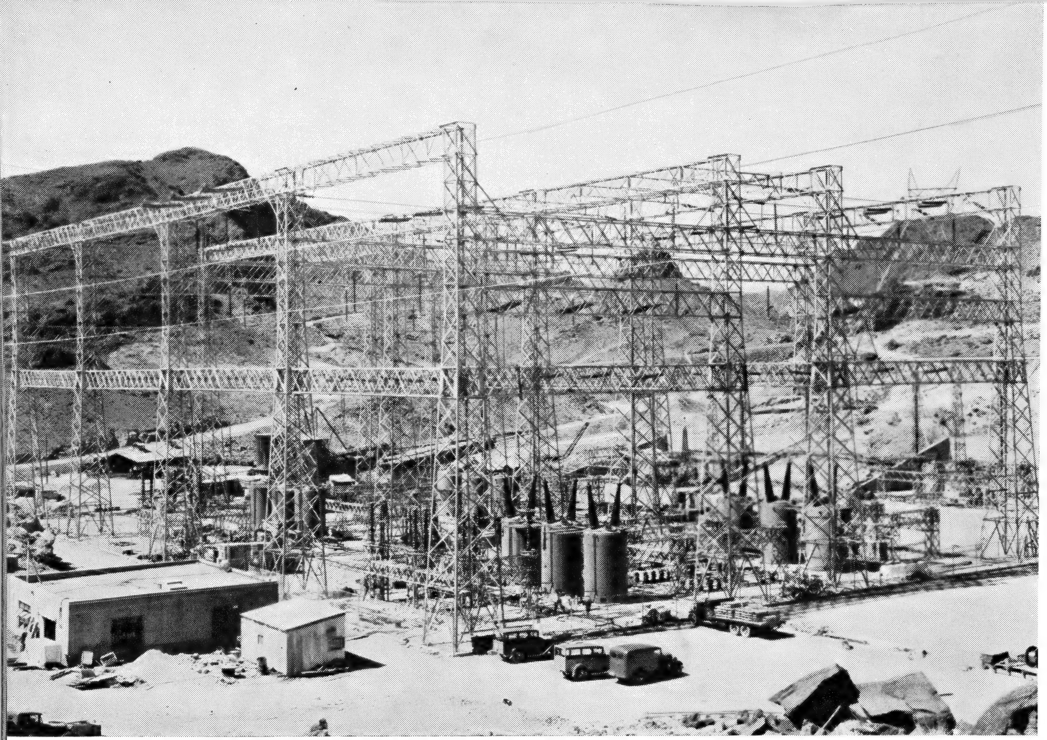
Spillway on the Arizona side. Dimensions: 650 ft. long; 150-ft. wide and 120 ft. deep. Four steel drum gates, each 100 ft. long and 16 ft. high, are installed along the crest. Spillway capacity—200,000 sec. ft. of flow. The dot at the bottom is a man.



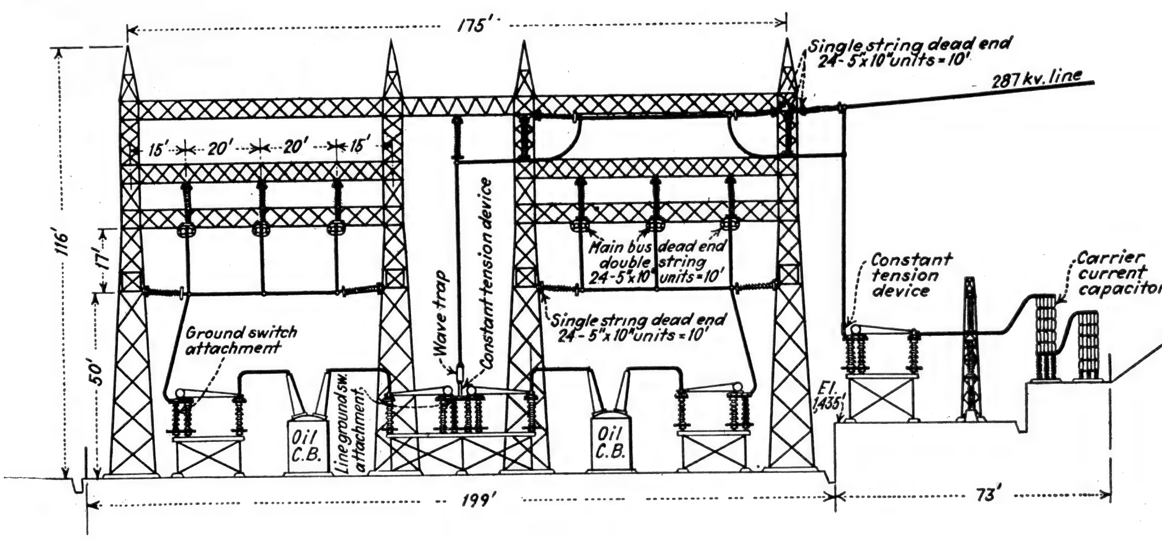
Night View of the cascade flowing from the outlet valve houses in the canyon wall.

Outlet Valve House gate valve operator (lower left) and (lower right) the operating mechanism which controls the circular steel gates in the intake towers.

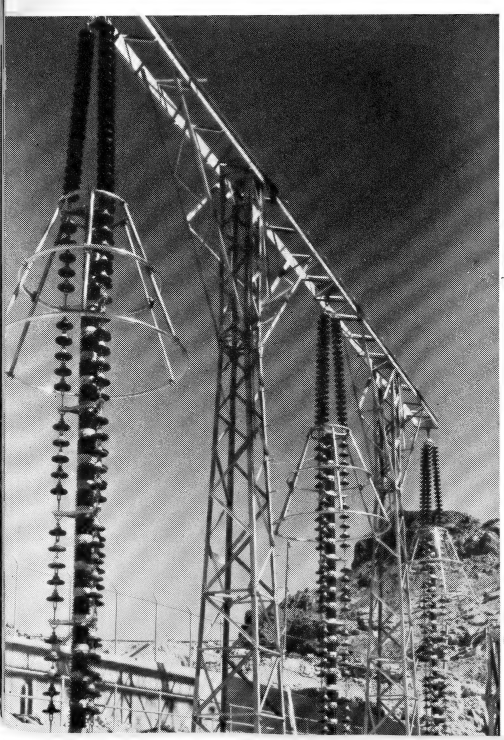




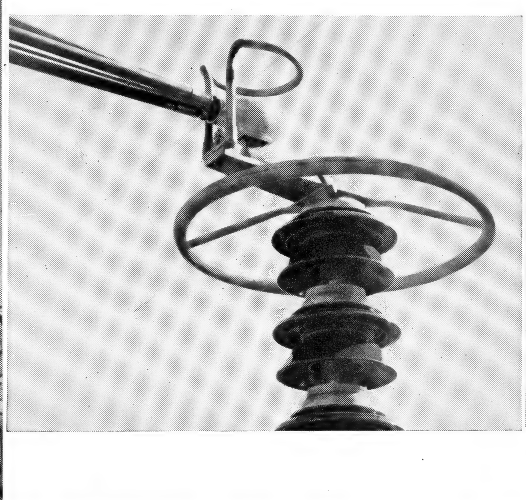
Boulder Dam Switchyard is located on the Nevada rim of the canyon. Each 287-kv. transmission circuit from the power house is connected to one side of the double bus that runs longitudinally through the switchyard. The double bus is cross-connected by a double set of disconnecting switches and high-speed oil circuit breakers, the midpoints of these two cross buses being the take-off points for the two circuits. The cross-section drawing below and the diagram on page 12 indicate the physical and electrical arrangement of circuits and apparatus.

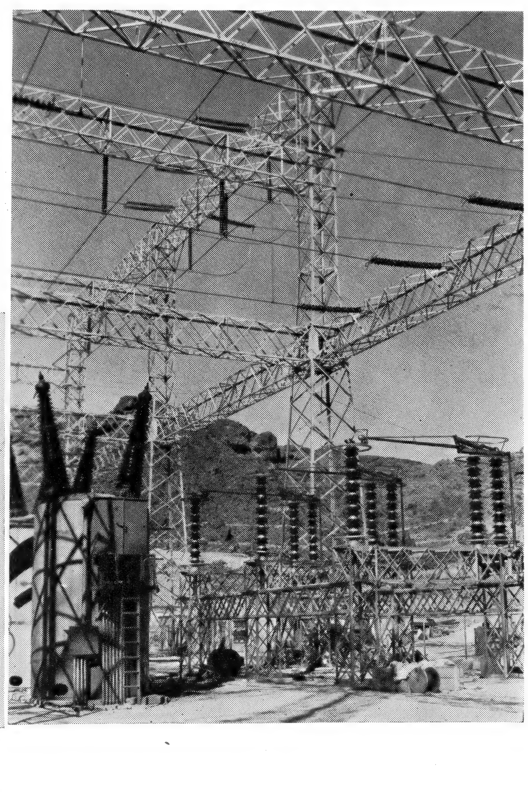


Lightning Arrestors for the switchyard and switching stations present an unusual appearance. The central column is the 287-kv. Thyrite arrestor itself being supported by the three strings of insulators around the outside. The bottom of the assembly is secured to the base through a spring tension to keep it from swaying. Electrostatic stresses are distributed over the entire length of the arrestor by the circular shield arrangement around the top.



Detail view (right) of one of the 287-kv. Bowie disconnecting switches and the Westinghouse high-speed de-ion oil circuit breakers which are installed in the switchyard. The breakers are designed to interrupt 2,500,000 kva. in less than 3 cycles. Close-up of the disconnecting switch contact (below) showing the protective hood over the moveable blade contact which protects against freezing and corrosion as well as decreasing the liability of corona formation.





287-kv. Chosen For Transmission

Utilization of Boulder Canyon power presented an entirely new problem to transmission engineers. Although the greatest amount of the Colorado's potential energy could be developed most economically at the upper Black Canyon site where the project is located, the primary market for a major portion of the electrical energy was in the metropolitan areas of Southern California almost 300 miles away. Studies concerning the transmission of the huge blocks of energy made available by the project early revealed that the conventional maximum transmission voltage of 220-kv. would not be practical from the economic standpoint, other elements such as stability, reliability and losses being considered.

At least two of the power distributing agencies rely upon the project as a major energy source for their power requirements. Reliability, therefore, is of prime importance. Equally important from the financial standpoint was economy both in investment and operating costs. Coordinating these two factors into the final design of the first two circuits from the Boulder Canyon project has resulted a very definite contribution to the technique of power transmission and has set a new standard for commercial practice for long distance, heavy duty transmission circuits.

As contractor for the power of the first four main generating units completed in the Boulder power house, the Los Angeles Bureau of Power and Light was the first distributing agency confronted with the problem of power transmission from the project. All credit is due to its engineers for successfully conducting the necessary research and development work, and for the independent pioneering that has achieved a design making the utilization of Boulder Canyon power economically feasible.

Reliability in transmission is affected by the electrical characteristics of the system and by external causes such as storms, accidents and mechanical failure. Dynamic stability or the ability of the transmission system and generators connected thereto to continue to supply power at normal frequency and voltage despite sudden changes in the electrical characteristics is most important in determining the maximum amount of power that can be transmitted over a given circuit. Factors affecting the stability are, among others, the voltage, electrical constants of the circuits, the electrical characteristics of the generating equipment and the speed with which faulty sections of line can be isolated from service. Stability calculations on the basis of the Bureau of Power and Light's 240,000 kw. allotment of power for voltages between 220 and 330 kv. indicated that with two 220 kv. circuits and 300,000 kva. of low reactance generators, the theoretical power limit would be 150,000 kw.; with three 220-kv. circuits, 280,000 kw.; and with two 287-kv. circuits, 265,000 kw. The two 287-kv. circuits were 17 per cent more economical than the three 220-kv. circuits. While, in theory, 330-kv. circuits would have had a still higher power limit, the costs of conductor and apparatus was prohibitive. Therefore 287-kv. was selected at the voltage for the Bureau's two transmission circuits. As the amount of power capable of being transmitted was increased 40,000 by low reactance generators, it was possible to justify a liberal design of the units which have a 17.5 per cent reactance and a short circuit ratio of 2.4 at 60 cycles, making it possible to transmit a total load of 300,000 kw. over the two 287-kv. circuits.

The rating of this transmission system is based upon its ability to interrupt a two-conductor-to-ground fault without losing synchronism. To accomplish this, faults must be tripped off the circuits within three cycles, a requirement heretofore thought impossible with the large equipment necessary for circuits of this capacity but one which has been met successfully by new designs of circuit breakers and relays.

Studies also revealed that sectionalizing the line into three parts by means of two switching stations increased stability and was economically justified over one sectionalizing station at the midpoint. Right-of-way and other considerations dictated the use of two single circuits from Boulder Dam for 225 miles and a double circuit tower line the last 40 miles.

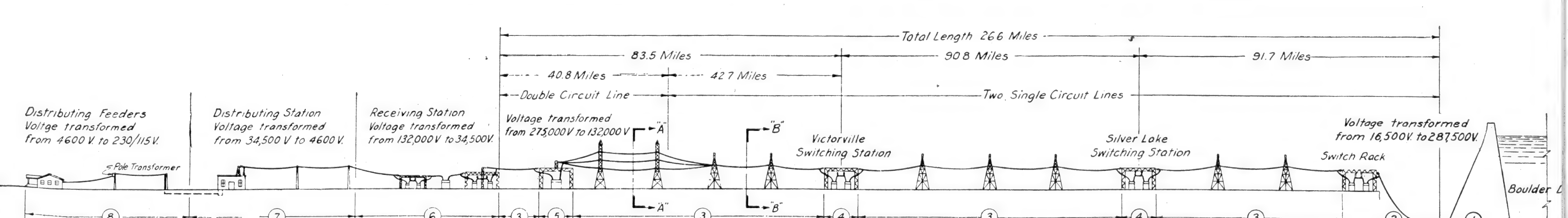
With these characteristics determined, attention was given to the design of equipment for this pioneer application of 287-kv. as a commercial voltage. Towers of sufficient height and strength to maintain clearances to permit economical span lengths with safety to the public and economy in investment had to be designed. Efficiency of transmission required a large diameter conductor (to limit corona losses) without an excessive copper area which would have increased both the cost of the cable and the size of the towers necessary to support the increased load. To fulfill this requirement a new type of hollow conductor was adopted and used for the first time in this country.

Efficient lightning protection for the line was devised through the use of two overhead ground wires and a counterpoise net buried under the circuits and bonded through an air gap to the legs of each tower. New switchgear, capable of rupturing the tremendous currents possible at short circuit in 0.11 seconds, had to be developed by the manufacturers. Transformers had to be designed for a new high voltage. Cable connectors, suspension clamps, practically everything associated with the line represents pioneer effort.

For control, communication and relaying, carrier current is used, there being four separate carrier frequencies superimposed on the transmission circuits. One is used for operation of the lock-out directional relay protective scheme; the second for supervisory control of circuit breakers and disconnecting switches at the switching stations; the third for telephone communication, and the fourth represents an innovation whereby communication is maintained with the patrol car maintenance crews by broadcast via the carrier current system. Switching control is normally from Boulder power house, but indications of switch positions also are carried to the main dispatching room of the Bureau of Power and Light in Los Angeles.

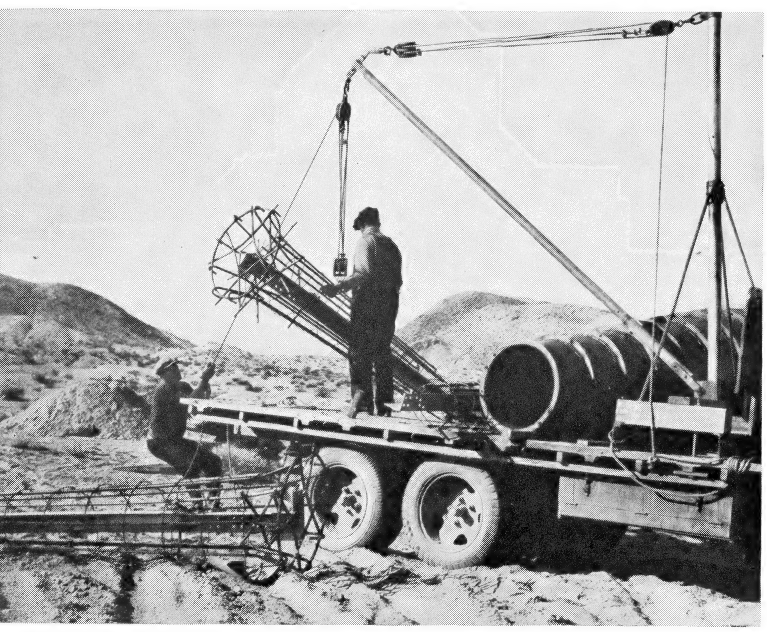
On succeeding pages will be found the engineering features of this pioneer application of 287-kv. recorded in pictorial form. The advanced design of the first of the Boulder Dam transmission circuits represents a definite step forward in the art of power transmission and widens the field for the effective and economical exploitation of water power resources everywhere.

Boulder Power Transmission Circuits of the Los Angeles Bureau of Power & Light



Forms of steel in the shape of a 30-deg. truncated cone were set in holes dug in the ground to provide reinforced concrete tower footings of the correct size for the new design of towers used on the 287-kv. transmission circuits. The excavation for these footings was undercut to develop maximum resistance to uplift in largely undisturbed soil. For single-circuit towers the concrete footing is 7-ft. deep and has a base diameter of 48-in. Tests of typical footings prior to erection of the towers confirmed the strength of the design.

Reinforcing Steel for the footings was fabricated as a unit in the field by electrically welding the steel bars around the angle iron stub to which the structural members above ground are bolted. A series of footing stubs of different lengths was designed to take care of the differences in soil, slope and other conditions of the terrain encountered along the route.

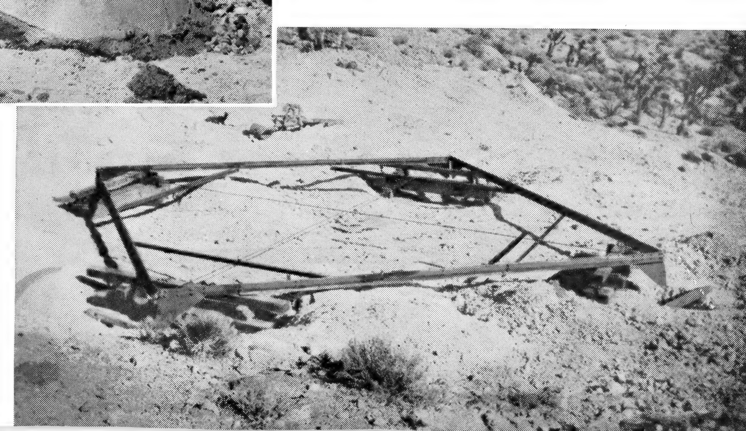


Placement of the forms and reinforcing steel was facilitated by the unit design. Steel forms and reinforcing units were easily transported in groups by means of trucks to the various locations. Light tackle rigged on the truck simplified loading and unloading and speeded the erection procedure.

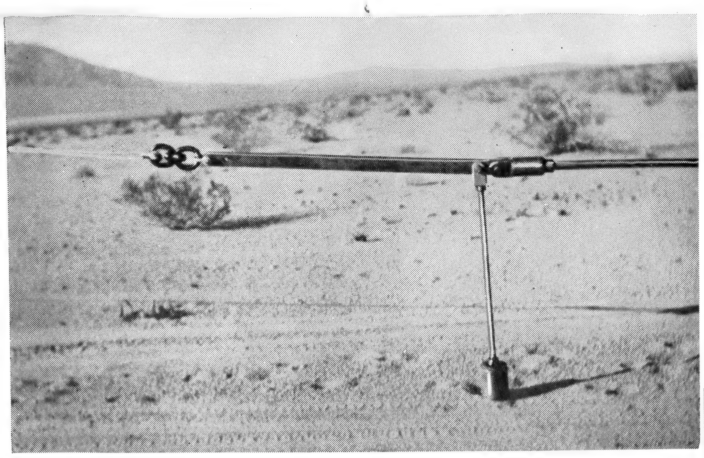
Concrete Mixing (left above) was complicated by the lack of water in the desert area. Special, truck-mounted portable concrete mixing plants of a very compact design were developed to expedite concrete placement in the forms of the tower footings. Sand and aggregate were found in suitable quantities and qualities at several locations along the route. Continuous testing of representative samples of concrete being used in the footings insured the requisite strength was being maintained. Waterproofing was applied to the exterior of the footing before the backfill was made and the footing left for the steel erectors.

TOWERS

Completed Tower Footing ready for the assembly of the tower steel. Concrete is carried well above the ground line to protect the member from corrosion. In this view the exterior surface of the concrete has been treated with a waterproofing compound and the backfill made.

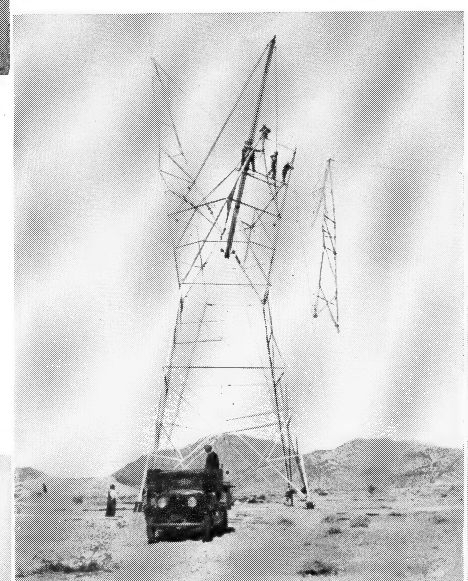


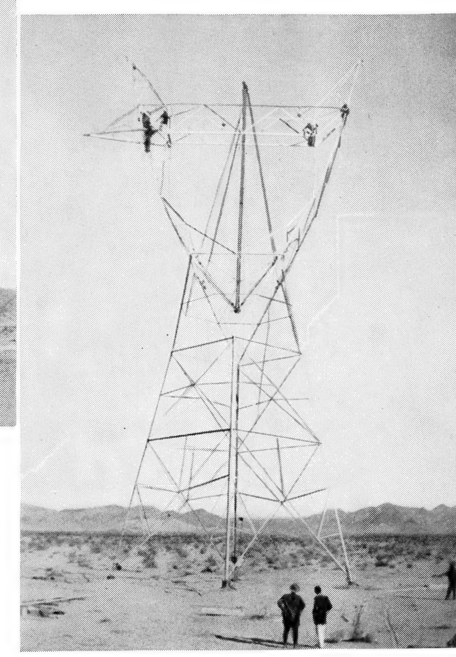
Templates of steel, to which the studs of the footings were bolted during their construction, insured correct alignment for subsequent operations. Templates consisted of a light angle iron frame suitably reinforced to maintain rigidity.

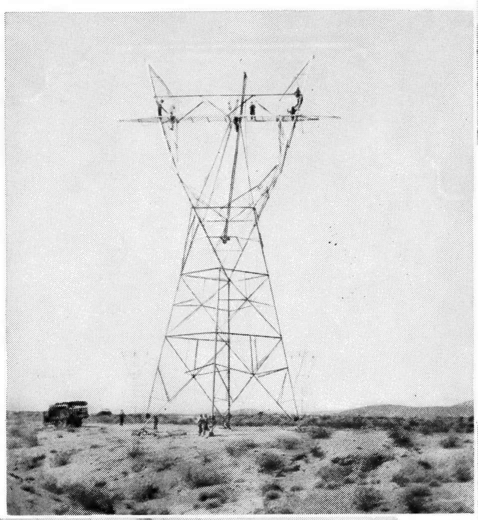


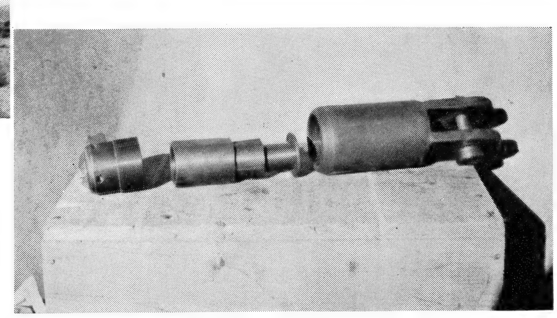
Tower Erection was accomplished in sections which were assembled on the ground, raised into position, and bolted into place. Special rigging on a light stiff-leg derrick which was raised with the steelwork facilitated erection. Single circuit towers are of the narrow-waisted type with the base rotated 45-deg. with respect to the direction of the line. Several tower designs were investigated but the rotated base type with the narrow waist was slightly lighter for the same strength and required smaller footing reactions which permitted economies in the design of the footings. The base of these towers is 32-ft. square; the overall height to the ground wire supports, 109 ft. 2 in.; overall width of the crossmember supporting the insulator strings, 65 ft. Views of completed towers of various types will be found on page 28 together with detailed specifications.

Counterweight device used to maintain the cable in proper position during the stringing operations. This innovation was one of the many new contributions to transmission line technique made necessary in designing the first line for 287-kv. operation. It prevented possible twisting action of the cable due to its segmental spiraled construction.

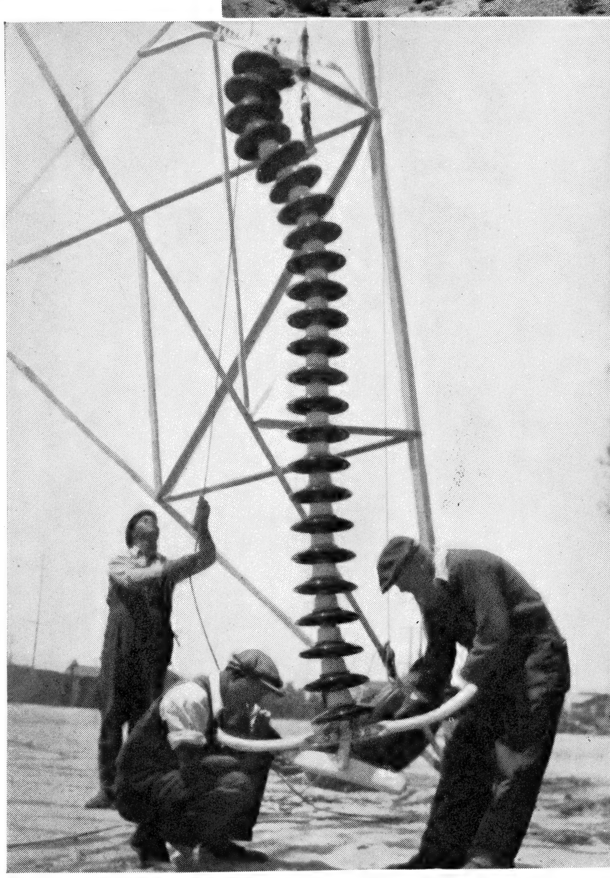








Hardware for the 287-kv. line also demanded a new design without the benefit of precedent or previous experience. This is a dead-end clamp utilizing the clamping action of a tapering sleeve to provide the requisite mechanical strength in holding the tubular conductor in position.

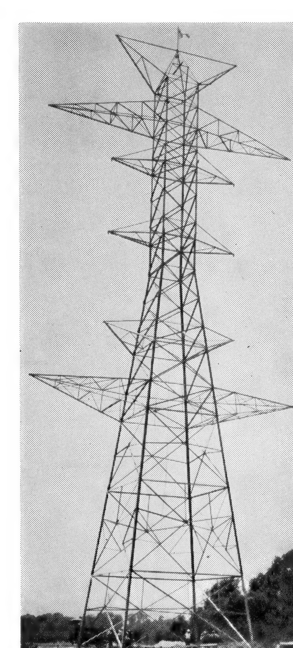


X

Insulator String for a tangent suspension tower consists of 24 10-in. Ohio Brass insulator units spaced 5-in. apart. In the selection of the length of insulator string, lightning flashover values rather than normal operating voltage are the criterion. Insulation value for this line was coordinated with the overhead ground wire-counterpoise protection against lightning and is designed to limit power arcs following lightning flashovers to minimum values despite the fairly frequent lightning storms experienced along the route of the line.

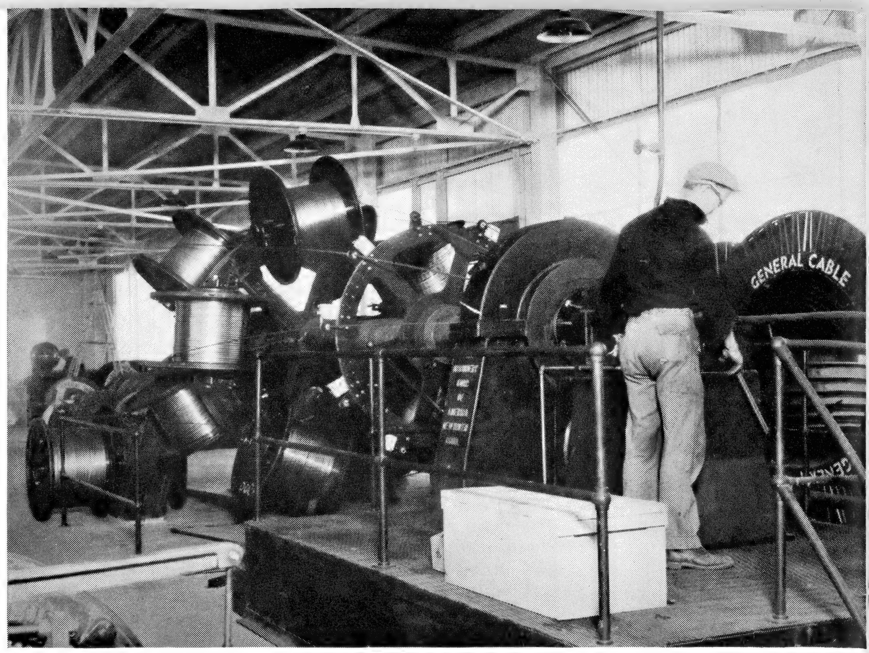
Arcing horns 30-in. in diameter in the plane of swing are mounted at either end of the insulator string, the lower arcing horn being 1-ft. above the conductor. For a wind pressure equivalent to 40 miles per hour velocity, a full clearance of 11 ft. between the conductor and the tower is maintained. Under a wind pressure of 12 lb. per sq. ft., the minimum clearance is 7 ft., which is 4½ times normal operating voltage and considered sufficient protection against switching surge flashovers.

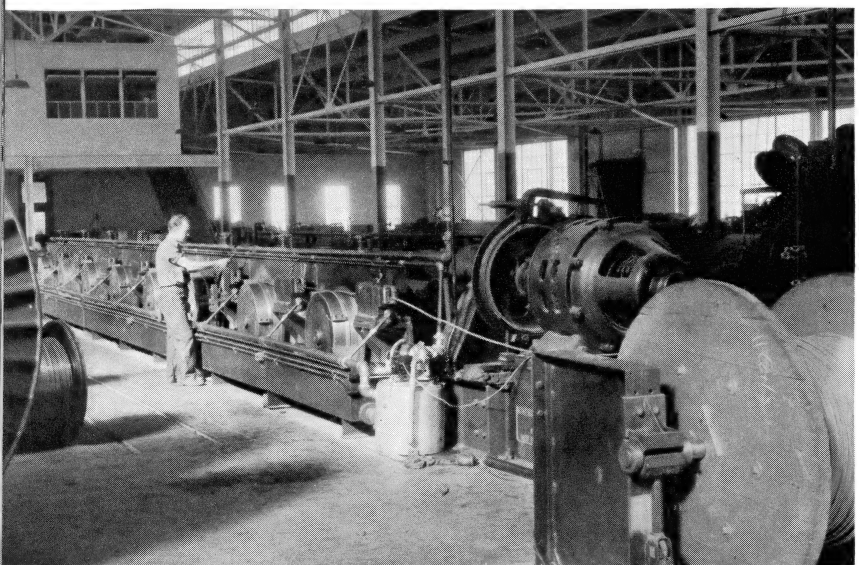
Transposition tower for double circuit section.



over

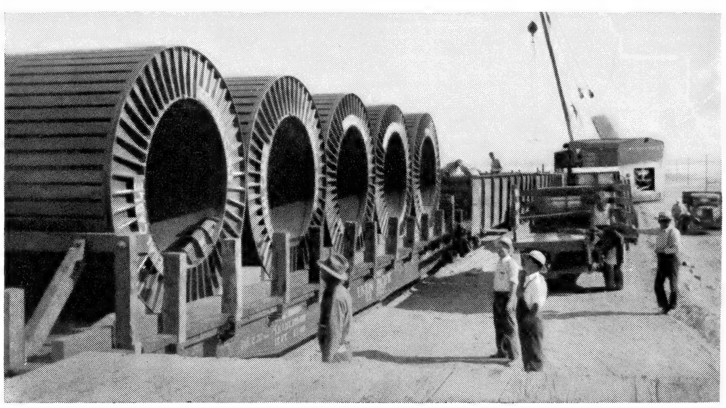
Conductor selection for a line operating at 287-kv. also was without precedent. At this voltage, the diameter of the conductor must be large enough to limit corona formation and attendant losses to a reasonable figure. A large diameter, however, implies a much larger cross section of copper than is necessary for transmitting the current economically. Numerous designs, incorporating various methods of limiting copper area and weight without sacrificing strength or the diameter of the cable, were tested. The design finally selected was originally a German development manufactured in this country by the General Cable Co. under the designation "Type HH." It is of tubular construction, 1.4 in. in diameter and the size used on this line has a copper area of 512,000 circ. mils

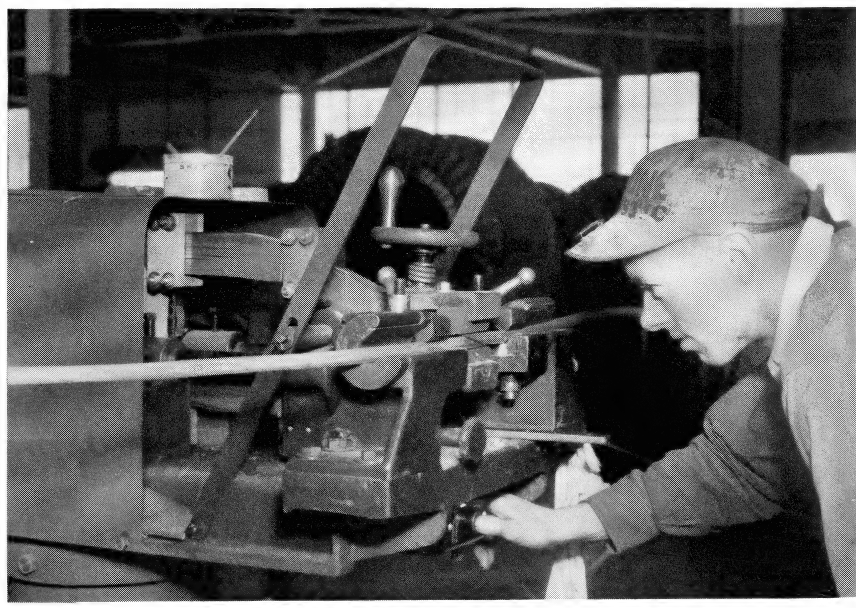


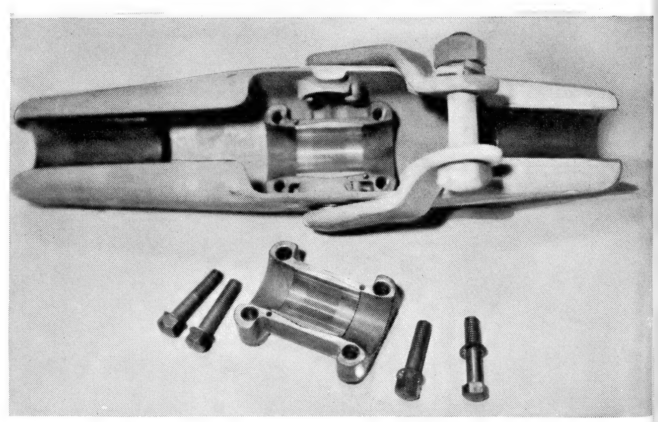


Forming the cable is accomplished in this machine which draws ten of the tongue and groove segments through a special head which closes adjacent tongues and grooves so that they are interlocked together in a spiraled form.

Drawing the segments is accomplished in the conventional manner with the exception that special dies which form a lip or tongue on one side of the segment and a corresponding groove on the other are used. The segments are drawn from copper rods welded together in the machine shown at the right to form a continuous rod one mile in length.

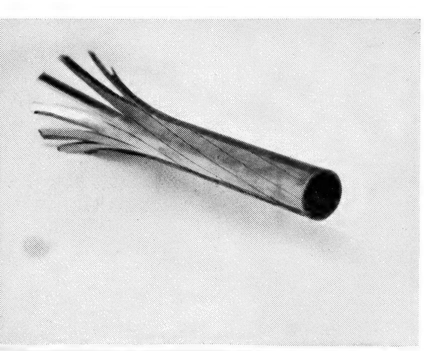


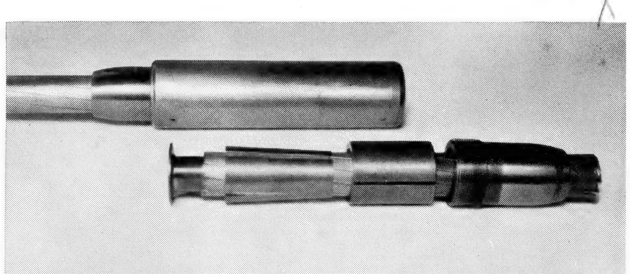




Connector for joining two pieces of the Type HH cable is of a new design. Extremely simple both in construction and installation, the connector consists of (1) an inner hollow plug which fits inside the conductor, (2) a tapered sleeve over which fits a (3) mating taper sleeve driven by (4) a threaded plug. This latter screws into the outer sleeve common to the two halves of the joint.

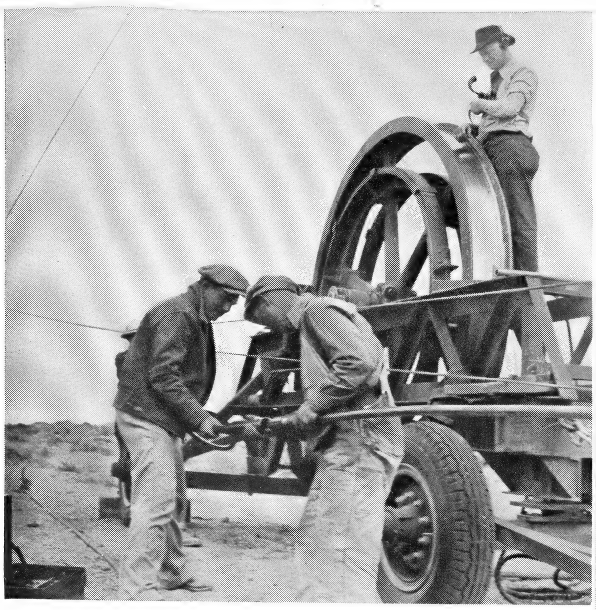
Cable view showing the ten copper segments being drawn down, interlocked and forming the smooth-surfaced hollow conductor. The spiral construction is clearly evident. Diameter: 1.4 inches. Weight per ft.: 1.57 lb.

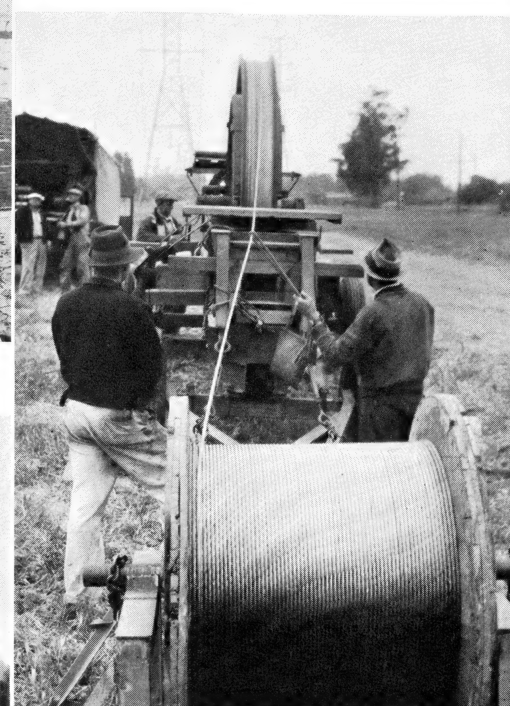


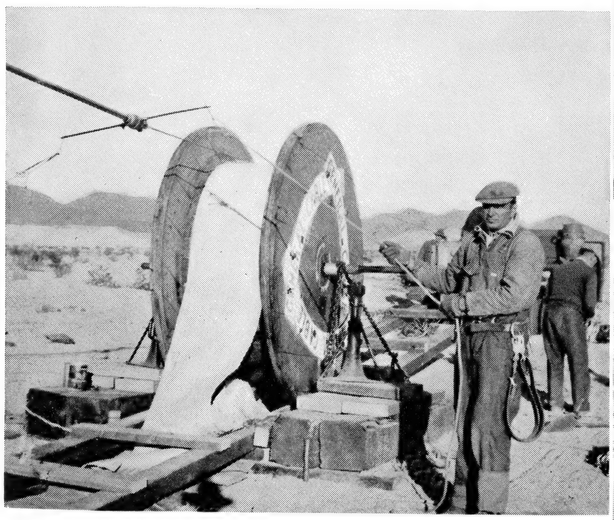


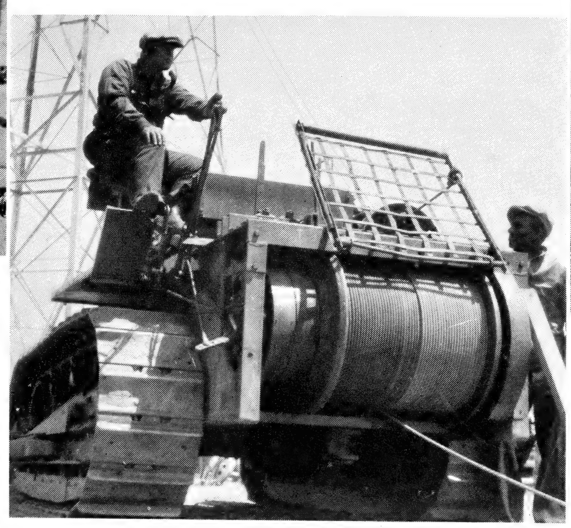
Suspension Clamp also was original in design and incorporates interesting features, not the least important of which is the "free center" suspension arrangement. The clamp consists of a metal shell at either end of which are two saddles supported on knife edges and free to rock in the vertical plane. On these the cable rests, the distance between the two centers of the saddles being one-half a spiral pitch of the cable. Attached to the cable and normally free from the clamp itself is the center clamping piece, consisting of a double conical wedge split in the center. Should the cable break, the clamping piece engages bosses in the shell and exerts clamping action on the cable through the wedge design.

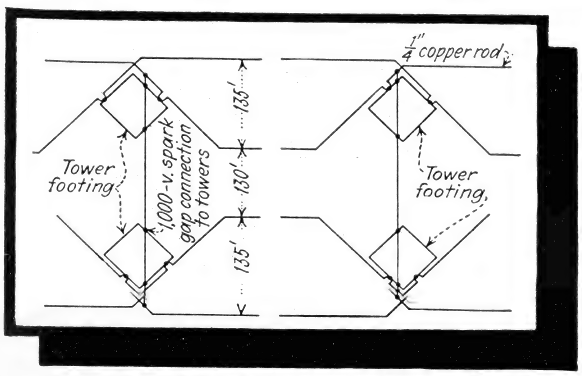
Cable Stringing was simplified with the special equipment shown in the accompanying views. At the upper left is shown the bull wheel around which several turns of cable were placed to maintain proper tension during the time the cable was being pulled into position. The cable was pulled from the reel set up behind the bull wheel, over the latter and attached to a steel messenger which was carried through the blocks suspended on the towers. The messenger cable terminated on the drum of a tractor-mounted winch located five spans away, the winch supplying the power required to pull the cable into position. Telephone communication was established between the bull wheel operator and the tractor operator. Care was exercised to prevent the cable from twisting by the use of counterweights and guide ropes during the stringing operations.





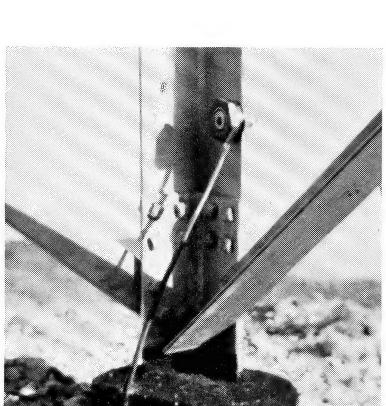


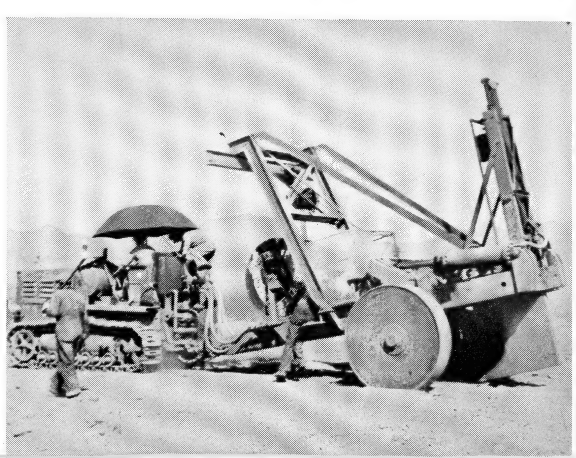


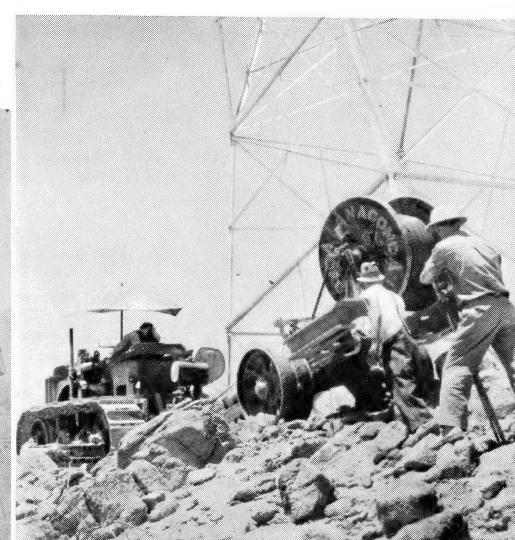


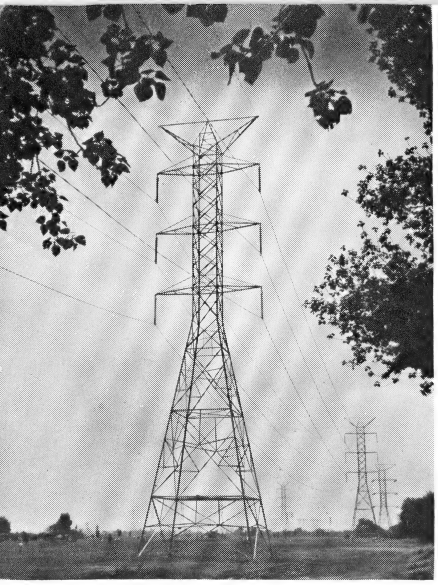
A Counterpoise was buried in the ground along the entire length of the transmission circuits as the best means of reducing tower footing impedance to between 17 and 25 ohms, the value which would reduce lightning flashovers to the desired value of a maximum of two per year per 100 miles of circuit. The counterpoise consists of two ½-in. black copper rods per circuit buried 3-ft. in the ground in the configuration shown in the accompanying diagram. This configuration combines the low surge impedance of the radial counterpoise with complete continuity. The counterpoise wires are cross-connected at each tower and bonded thereto at two points by means of a special connector bolted to the tower (see lower left). This connector consists of two parts separated by an air gap designed to break down under a 1,000-volt potential between the tower and the counterpoise wire. This permits ample protection in case lightning strikes the overhead ground wires and goes to ground through the tower but does not permit electrolytic corrosion which might be experienced in the alkali soil if copper and steel were bonded together.

A Counterpoise Plow buried and covered the counterpoise rod in one operation. The plow was pulled by a tractor and, in spite of the difficulties of terrain which were encountered along the route, operated very successfully and economically. The rod was carried on reels mounted on the plow as shown on the extreme right below.



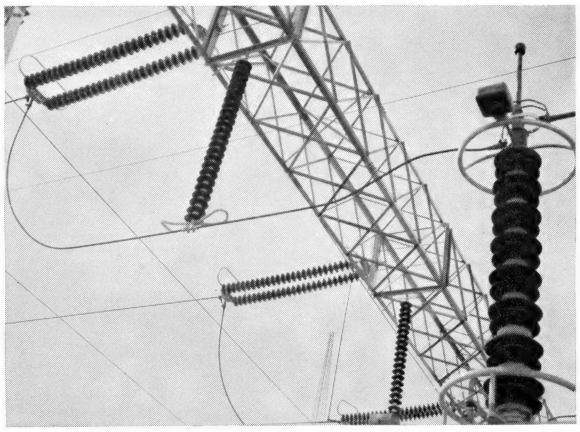






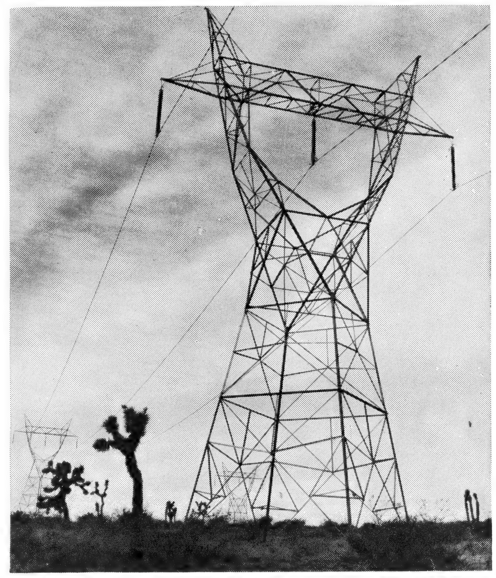
Double Circuit suspension tower typical of those at the western end of the line. These towers are 144 ft. high and have three 41-ft. crossarms located 24.5 ft. apart vertically, the lowest being 175 ft. above the ground. Groundwires are carried at the outermost ends of the upper member spaced 40 ft. apart. Circuit configuration is vertical, one three-phase circuit being carried on either side of the tower. These towers are designed for a maximum pull of 8,750 lbs. and provide minimum clearance between conductor and ground of 45 ft.

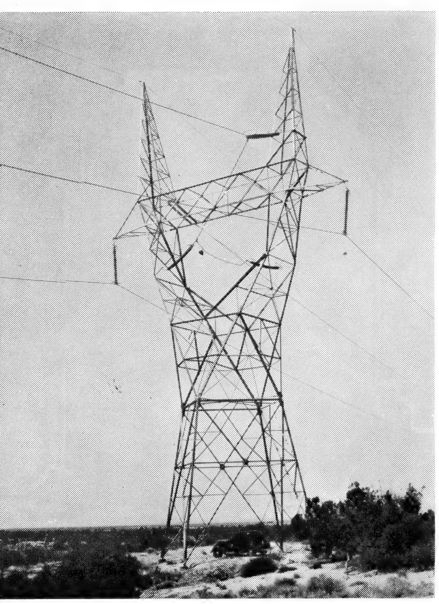
Detail (right) of the dead end arrangement at switching station terminals shows the method of supporting the conductor on a double string of insulators and then carrying it to the disconnecting switch terminal.



Single Circuit Tower of the suspension type. These towers are 109 ft. high, are built of steel having a high elastic limit, and will withstand a maximum loading of 8,700 lb., 40 per cent of the ultimate strength. Under normal temperatures of 60 deg. F., conductor tension is 4,370 lb.

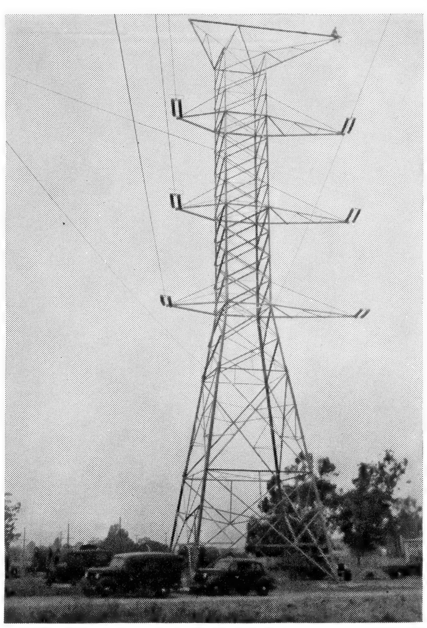
Overhead ground wires protect the conductors from lightning strokes, the ground wires being 7-strand galvanized steel mounted 32 ft. above the conductors with a horizontal separation of 50-ft. The use of two ground wires decreased the surge impedence, increased the coupling factor to the conductors and provides a more reliable shielding than could have been obtained with one ground wire without going to an uneconomical height.





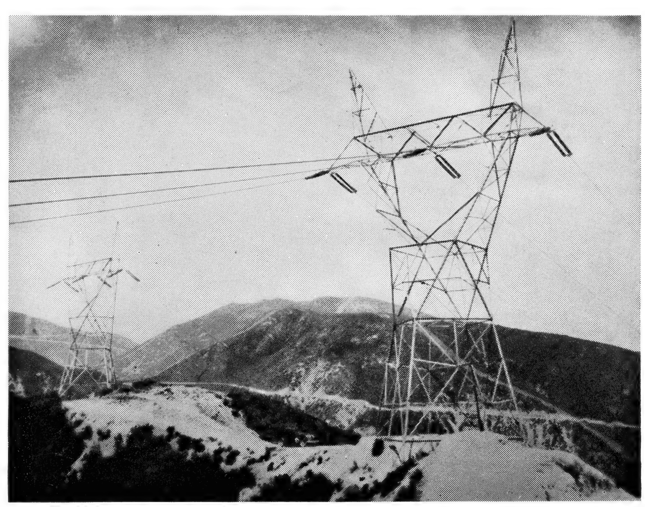
Statistics. The total number of single-circuit towers used in the line is 2,422 producing an average span of 984 ft. Maximum span: 1,811 ft.; minimum span, 431 ft. The total number of double-circuit towers used is 257 in a distance of 40.8 miles giving an average span length of 839 ft. Maximum span length: 1,620 ft.; minimum span length, 331 ft.

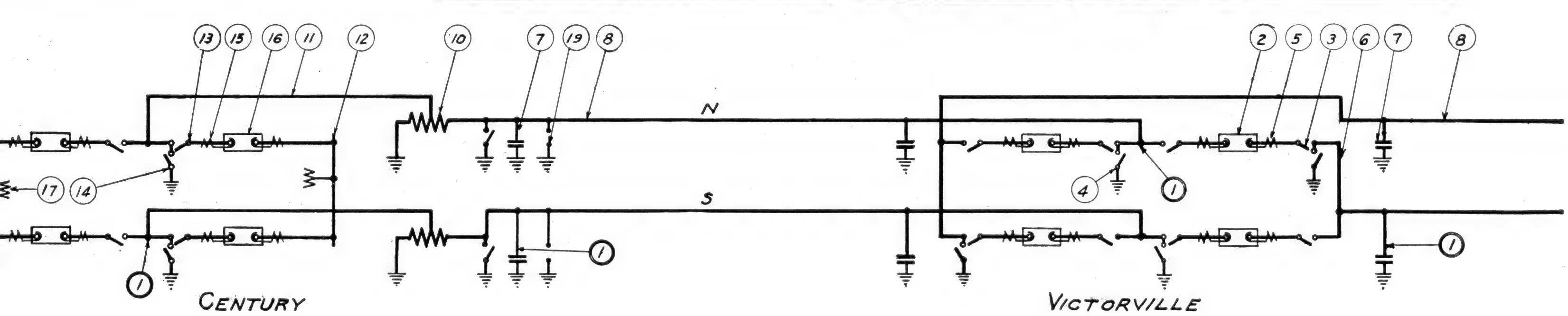
Angle Tower of the double circuit type shows the modifications of design of the crossarms to meet specific loading requirements.



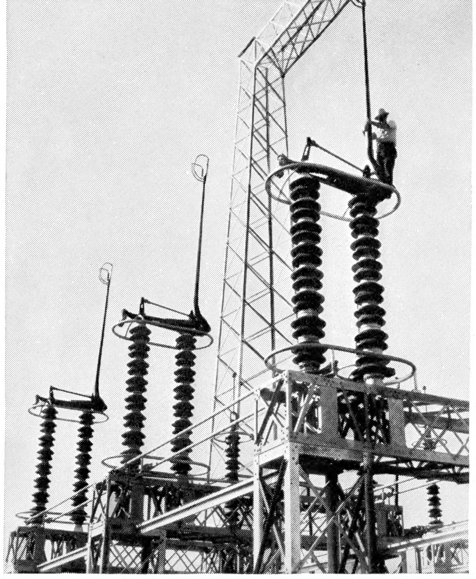
Transpositions on the two single circuits were accomplished by the design of towers shown above and spaced every 30 miles in the sending end and middle sections of the line to give a complete "barrel" transposition. On the double circuit towers, possibilities of interference with communications circuits require three "barrel" transpositions. All transpositions both on the single and double circuit towers were made by a re-design of the standard tower.

Dead-End Towers of the single circuit design. Both circuits are visible in this photograph and close inspection will reveal an automobile near the closest tower which provides a medium of estimating the tremendous size of these structures.

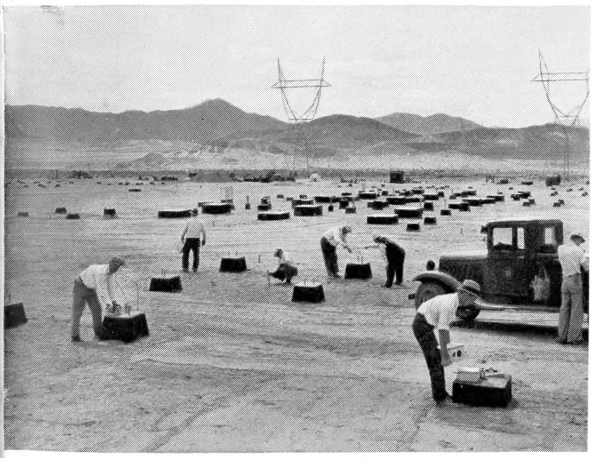




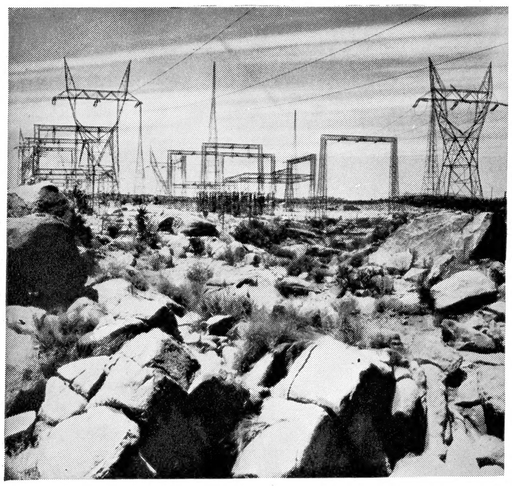
Stability requirements dictated the use of two switching stations dividing the transmission circuits into thirds. These stations primarily permit isolation of a fault by cutting out 90 miles of circuit, the transmission circuits being designed with sufficient capacity so that one circuit can carry the full output from the four Boulder canyon generators without exceeding the power limit of the system. The switching stations consist essentially of high-speed oil circuit breakers and disconnecting switches all of which are operated normally through supervisory control from Boulder power house. The new design of circuit breakers, described elsewhere on this page, does not require the conventional concrete platform for installation, concrete footing blocks being all that are necessary. Thus it is that the foundations for the equipment at these switching stations as shown below is of a very unusual appearance.



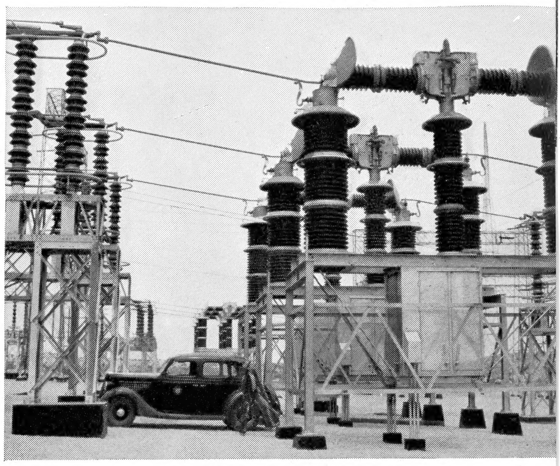
Detail of the 1,200-amp., 287-kv disconnecting switches, built by Delta-Star Electric Co., used in the switching stations. The switches are gang operated and are shown here in their open position.

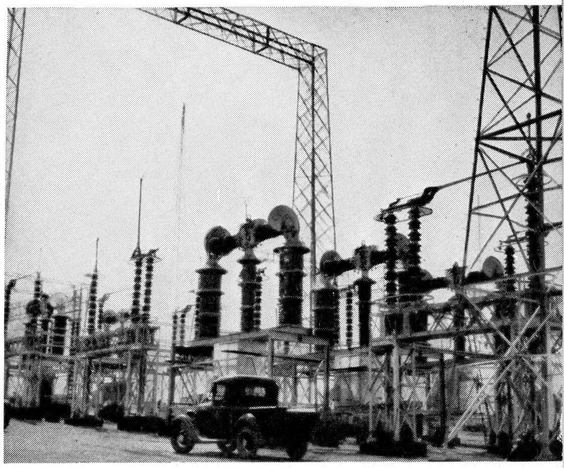


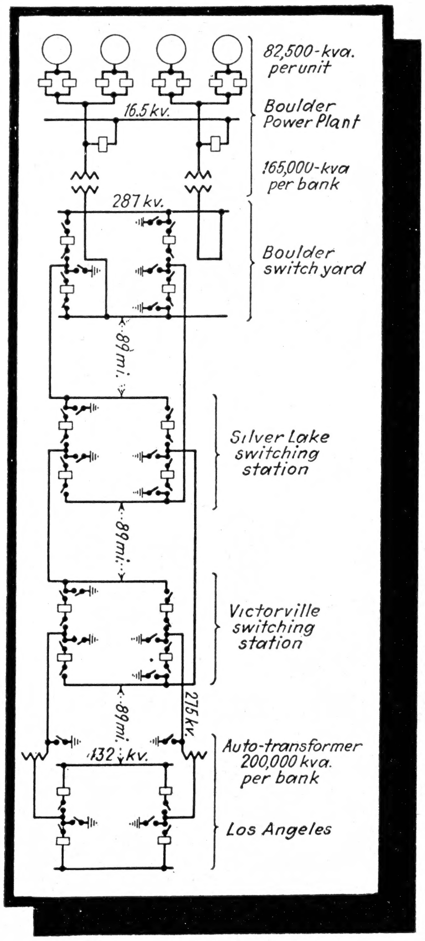
General View of the equipment in one of the switching stations. In the center will be seen a high structural steel tower called a diverter tower the purpose of which is to protect the station from direct lightning strokes. Four of these towers are installed at each station and provide the terminals for the overhead ground wires. Under the station, the counterpoise wires are fanned out into a protective network which is bonded to the diverter towers.



New Oil Circuit Breakers were designed by General Electric engineers to meet the ultra-high speed switching requirements of the system. These breakers are of the impulse type and will interrupt 5,000 amp. at 287 kv. in less than 3 cycles or 0.11 seconds. They have eight breaks in series housed in the horizontal insulating tube. As the breaker opens, impelled by a strong spring, oil under 100-lb. pressure is forced across each break to extinguish the arc formed there. Each 3-phase group of single phase units occupies an area 22x54 ft. and stands 27 ft. high. Only 2,600 gallons of oil, approximately 10 per cent of that required by a conventional breaker of this size, is required for a 3-phase unit. Of this amount only 210 gallons are exposed to the arc. This feature preserves insulating qualities of the oil, limits the weight of the switch, and simplifies oil handling in isolated locations such as those of these desert switching stations.

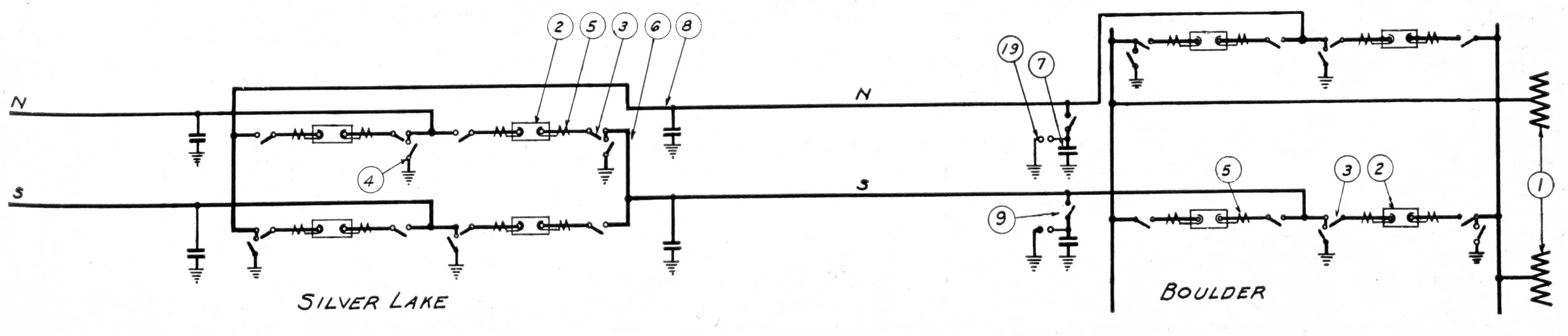




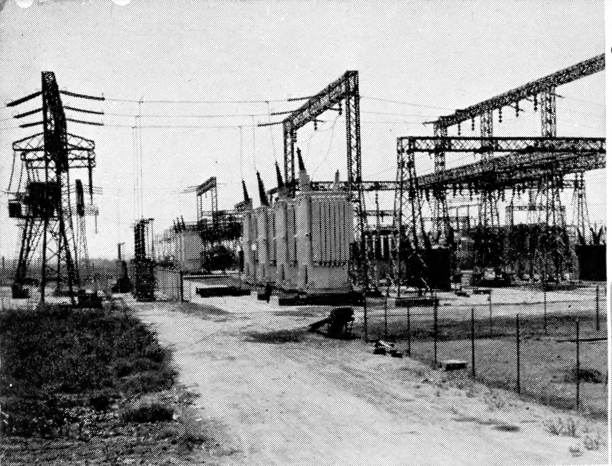


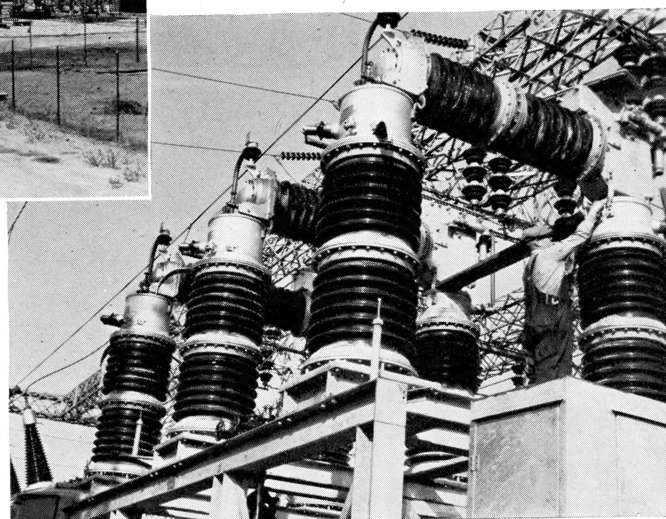
One Line Diagram of the transmission circuits (above) showing the general relationship of the generating and transmission system and the connections at the various switching centers.

Key to the circuit diagram below. Important apparatus indicated by numbers is (1) main transformers; (2) high speed o.c.b.'s; (3) 287-kv. disconnects; (4) ground switch; (5) current transformer; (6) 287-kv. bus; (7) coupling capacitor for carrier current. The other numbers indicate similar equipment on the 132-kv. circuits at the receiving station.



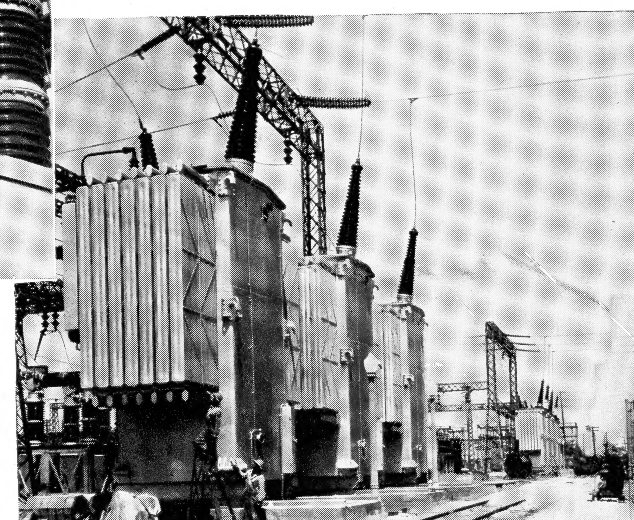
RECEIVING

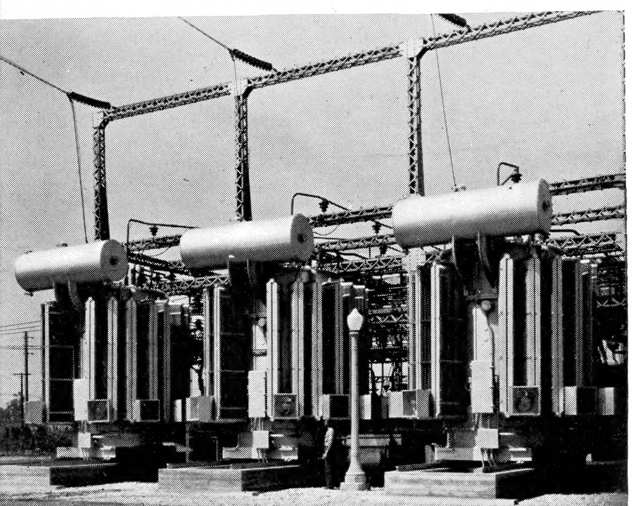




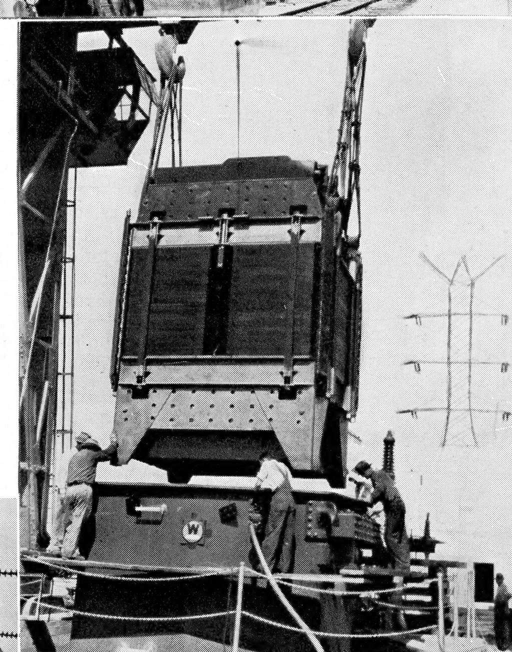
Terminal Rack at Receiving Station "B" of the Los Angeles Bureau of Power and Light where Boulder Canyon transmission circuits feed into the 132-kv. transmission loop around the city.

Impulse Breakers (left), rated 1,200 amp., 132-kv., having an interrupting capacity of 2,500,000 kva., are connected between the step-down transformer bank and the 132-kv. bus of the station.



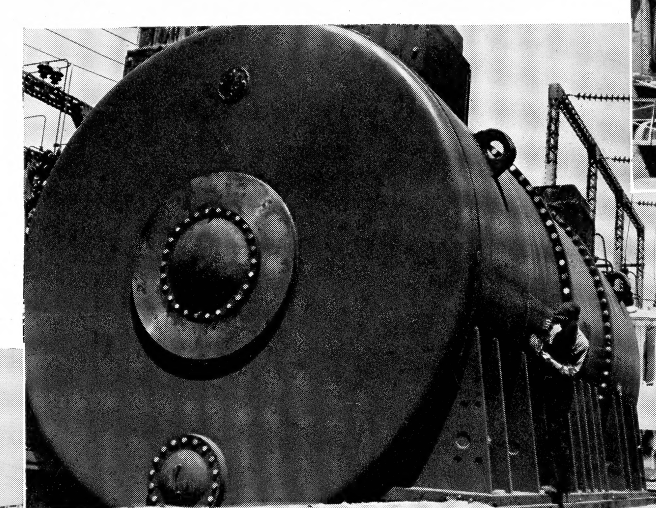


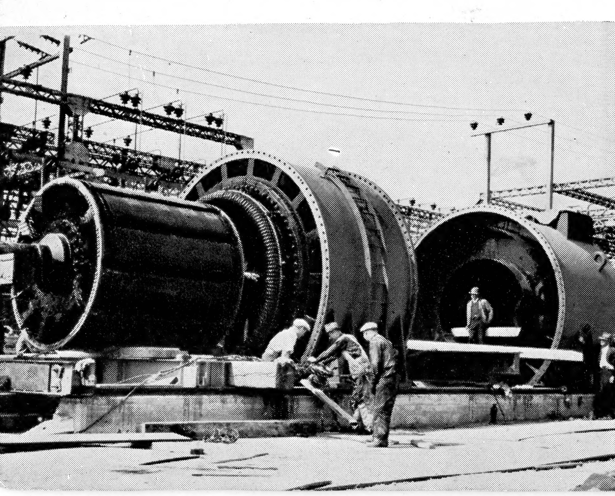
Receiving End autotransformer banks (right) are connected on the high voltage side, directly to the transmission circuits. Each of the two incoming circuits has an individual transformer bank. At this point the receiving end voltage of 275-kv. is reduced to 132-kv. These transformers are rated for 48,750 kw. without blowers, 65,000 kw. continuous with blowers and 80,000 kw. for 2 hours with blowers. Each bank, therefore, can carry 240,000 kw. for emergency periods, this being the combined capacity of the four main generating units connected to the transmission system at Boulder power house. Built by Westinghouse, these units are the largest auto transformers ever constructed, weighing 332,000 lb. and requiring an installation space 23½ x 36 x 11½ ft. Continuity of service being important, these units are protected on the primary side by 275-kv. autovalve lightning arrestors.



Power from the 132-kv. bus is further reduced in voltage by four banks of transformers, one of which is shown above. These units are forced air cooled and have three windings, the primary rated at 60,000 kva. and 132 kv. star; the secondary rated 80,000 kva. at 34.5 kv. star; and the tertiary rated 60,000 kva. at 13.2 kv. delta, the latter providing the connection for the 60,000 kva. synchronous condensers installed for voltage regulation of the line.

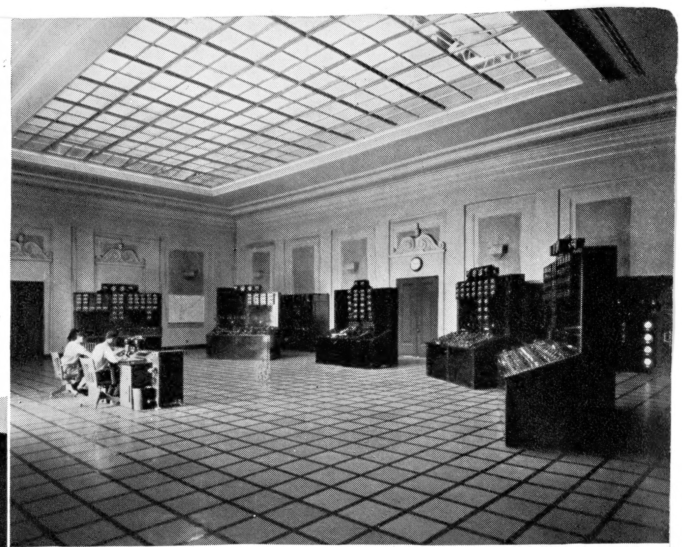
Lowering the core into the tank of one of the 275/132-kv. transformers. A special gantry crane, one of the largest in the world, was built at Receiving Station "B" to handle this equipment.



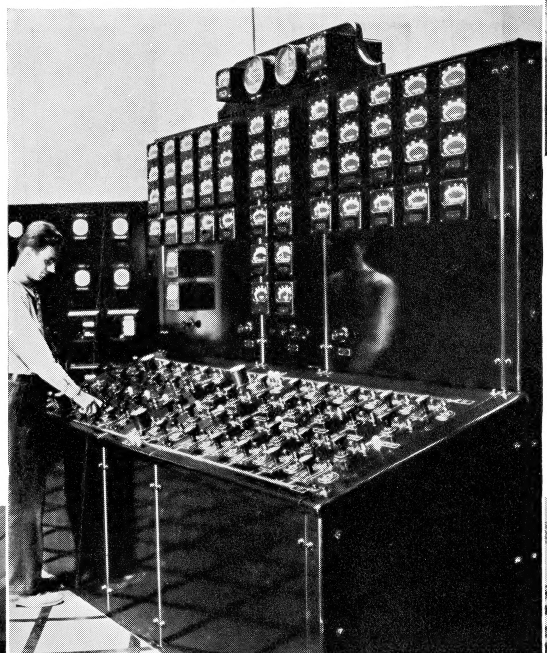


Four Synchronous Condensers, each rated 60,000 kva. leading, 36,000 kva. lagging are installed at the receiving station and connected to the system through the tertiary windings of the 132/34.5 kva. transformer banks. Condensers are hydrogen-cooled, outdoor type, manufactured by the General Electric Co. 13.2 kv. connections are made to transformers on tubular copper busses installed in a tunnel under the station. Auxiliaries are installed in a condenser pit directly below the machine.

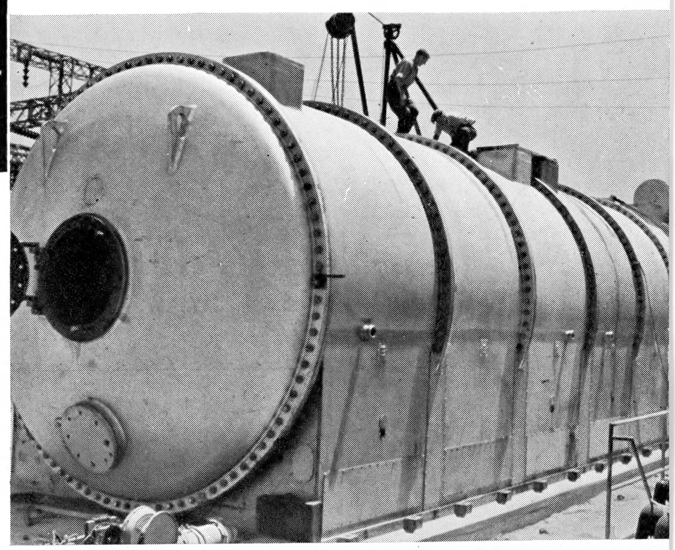
STATIONS



Control Room of Receiving Station "B" in Los Angeles. Here, not only the switching for the receiving end of the Boulder circuits but also the control of the 132-kv. switchrack and incoming circuits from existing plants and the control of outgoing 34.5 kv. distribution feeders, is centralized. Left—A close-up of the bench type control board for the Boulder Power circuits.

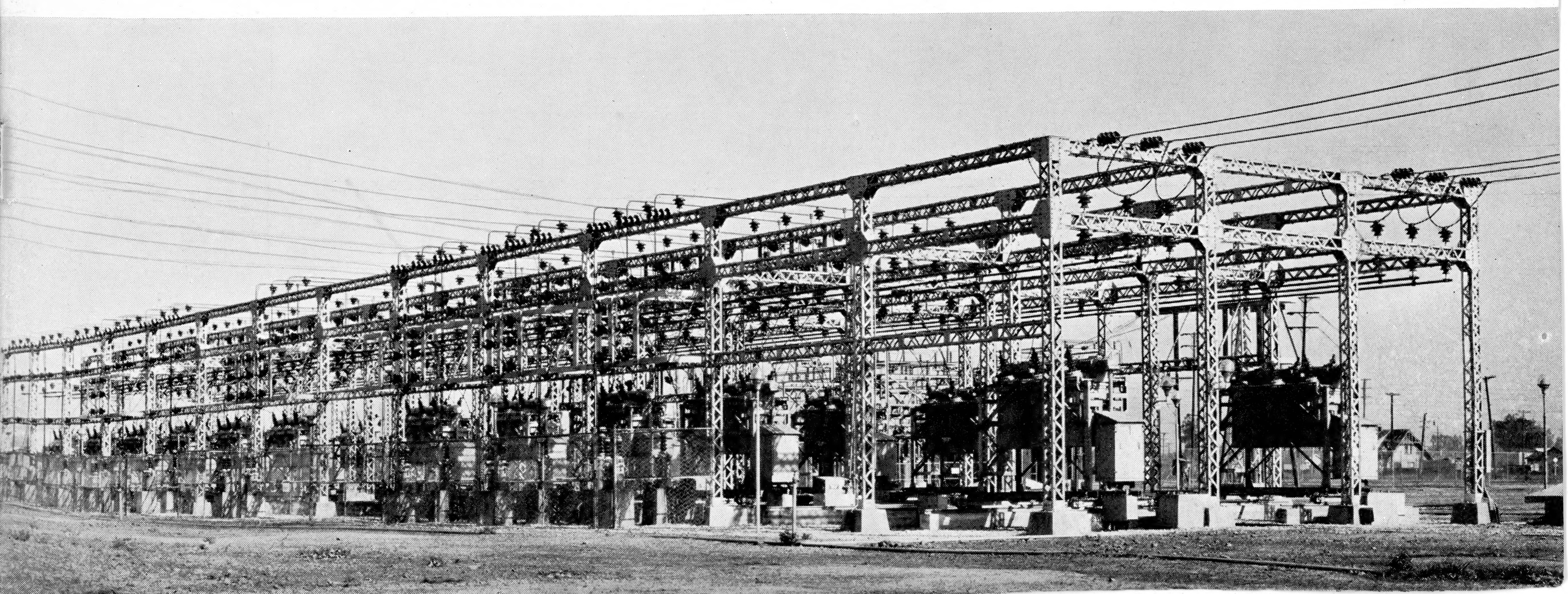


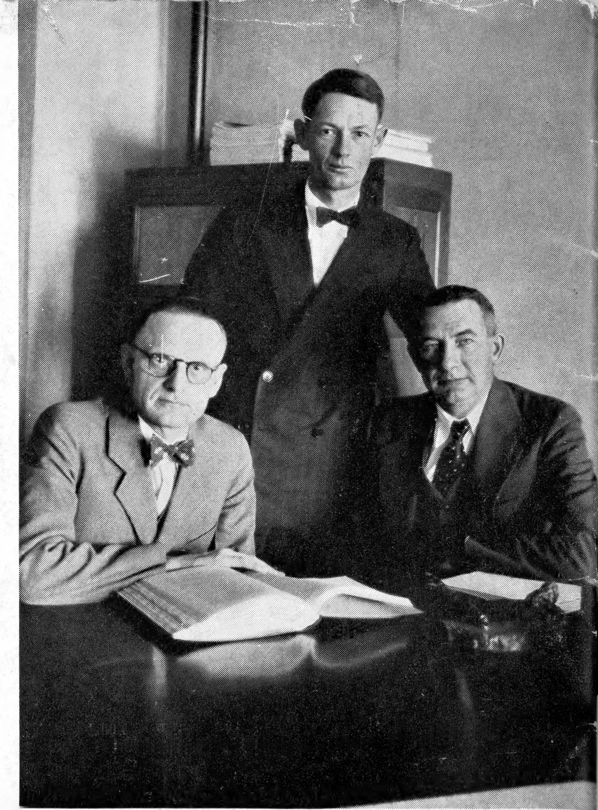
Cable Tunnel under the receiving station showing the method of supporting the multi-conductor, lead-covered control cables in their runs to various points. A relay board is shown at the left.



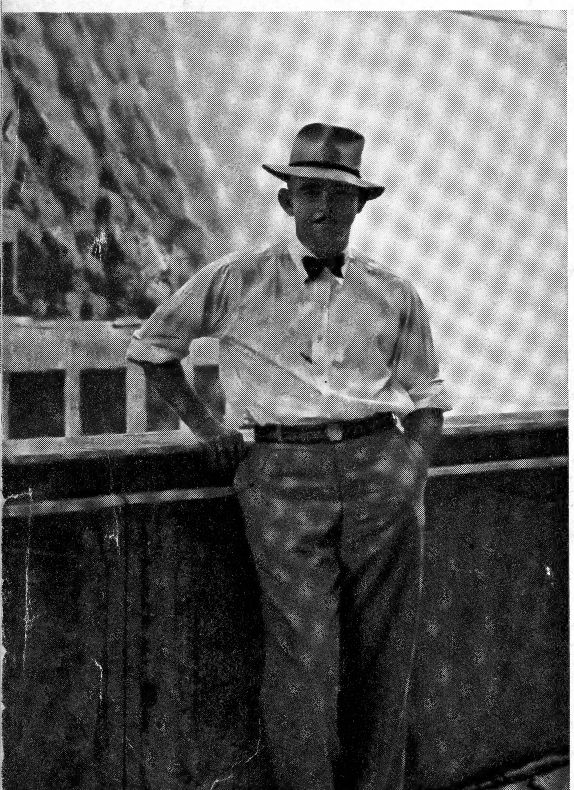
Frequency Changer, rated at 60,000 kva., is installed at Receiving Station "C" as a standby source of power. Normally this unit operates as a synchronous condenser, but, in emergencies, can be switched over quickly as a frequency changer taking 50-cycle power from the Southern California Edison Co., Ltd., and delivering 60-cycle energy into the Bureau's system which is now being changed over to the latter frequency.

Typical 34.5 kv. double bus switchrack at a receiving station. Each receiving station is designed for an ultimate of four of these 10-feeder switchracks supplied from the 132-kv. station bus through step-down transformers.





PERSONALITIES OF THE PROJECT



Officials of the United States Bureau of Reclamation and the Six Companies, Inc., of San Francisco. (Above left) From left to right: N. S. Gallison, H. J. Lawler of the Six Companies; Walker Young, Construction Engineer for the USBR; C. A. Shea and E. O. Wattis of the Six Companies; Dr. Elwood Mead, Commissioner of the USBR at the time the project was started who died in office during its construction; F. T. Crowe, Supt. of the Six Companies operations; R. F. Walter, Chief Engineer of the USBR, Denver, Colo.; and W. A. Bechtel, executive of the Six Companies organization.

Informal photograph of the USBR's top executives in Boulder City. (Above right) Seated (left) Walker Young, Construction Engineer from the start of the project until 1935 when he was transferred to take charge of the huge Central Valley Project of California. Standing—John C. Page, Acting Commissioner of the United States Bureau of Reclamation, Washington, D. C. Seated (right) Ralph Lowry, who succeeded Mr. Young as Construction Engineer, having served as Field Engineer since the start of the project.

To A. C. Wingo (left center) of the Los Angeles Bureau of Power and Light, will fall the responsibility of the operation of Boulder power house. His title will be "Division Superintendent of Generation" with headquarters at Boulder City.

(Below right) Los Angeles Bureau of Power and light executives: (Left) C. P. Garman and (right) E. F. Scattergood, Chief Electrical Engineer and General Manager of the Bureau.

F. O. Bolser (below center), design engineer of the Los Angeles B. of P. & L., was responsible for many of the new developments required for the transmission system. Here he is shown with the special suspension clamp he designed for the Type HH cable used on the line.

H. C. Gardett (right center) head of the Bureau of Power and Light's Department of Design and Construction, under whose direction the pioneer 287-kv development was carried on.

Left to right: H. J. McCracken, W. S. Peterson and Bradley Cozzens, Transmission Engineers of the L. A. Bureau of Power and Light (below left), whose research work contributed much to the advancement of the art of high voltage transmission.